Resource Allocation in Wideband CDMA Networks for High Data Rate Applications

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Certificate

This is to certify that the work contained in the thesis entitled ***Resource Allocation in Wideband CDMA Networks for High Data Rate Applications,*** by Mr. Gaurav Sharma (Roll no. 9810419) has been done under my supervision and that this work has not been submitted elsewhere for a degree.

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Words are not enough to explain my feeling towards my Parents. I always found them standing by my side during my hard days. They have always been the constant source of inspiration for me.

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Dedicated to

My Parents

Abstract

Present generation wireless networks are being designed considering voice as primary traffic. After the advent of the Internet era, demand for high data traffic over mobile networks is increasing. Third generation standards are proposed to meet the increasing data traffic demand over mobile phone. Code division multiple access (CDMA) is a promising technique for radio access in the future cellular networks and personal communication systems. CDMA in cellular systems offers some attractive features, such as high spectral efficiency, soft capacity, diversity, simplified frequency planning, etc. All the third generation CDMA standards are called Wideband CDMA because of their wider access bandwidth.

In case of Internet access, flow of traffic is generally from a remote server to a user terminal, which constitutes downlink traffic for wireless networks. Power transmitted for a user depends on the bit rate and interference conditions. Base stations are total power transmitted limited. To support multiple bit rate traffic, power allocation at the base station becomes vital.

This thesis deals with the problem of resource allocation in the forward link for Wideband CDMA networks. Users with data rate of 9.6kbps, 144kbps, and 384kbps are considered with a system bandwidth of 5MHz, operating in 2GHz band. We have proposed three Power allocation algorithms, which are based on the load and interference calculations. Minimization of blocking probability for different user classes is the primary concern of the proposed algorithms.

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List of Abbreviations:

ACCH	-	Associated Control Channel
ARIB	-	Association for Radio Industry and Business
BPSK	-	Binary Phase Shift Keying
CDMA	-	Code Division Multiple Access
DCCH	-	Dedicated Control Channel
DS	-	Direct Spread
DTCH	-	Dedicated Traffic Channel
ETSI	-	European Telecommunication Standard Institute
FACH	-	Forward Access Channel
FH	-	Frequency Hopping
GPS	-	Global Positioning System
GSM	-	Global System for Mobile
IMT	-	International Mobile Telecommunication
ISDN	-	Integrated Services Digital Network
ITU	-	International Telecommunication Union
PCH	-	Paging Channel
POB	-	Probability of Blocking
QPSK	-	Quadrature Phase Shift Keying
SDCCH	-	Stand Alone Dedicated Control Channel
SNR	-	Signal to Noise Ratio
TDMA	-	Time Division Multiple Access
TH	-	Time Hopping
UMTS	-	Universal Mobile Telecommunication System
WCDMA	-	Wideband Code Division Multiple Access
WWW	-	World Wide Web

Chapter 1

Introduction

Wireless communication has become a focus of worldwide research and commercial activities. The advantage of code division multiple access (CDMA) for cellular traffic has become well known and Qualcomm (US) proposed IS-95 based system are now being widely deployed in several regions of world. Attention is now focused on higher data rate packet services for cellular system. Web browsing is an interesting as well as challenging example of high data rate traffic for mobile user. Third generation mobile radio network, often dubbed as 3G, have been under intense discussion following world wide research and are expected to get commercially exploited around the year 2002. In the international telecommunication union (ITU), 3G is referred to as International Mobile Telecommunication-2000 (IMT-2000), whereas in Europe it is being referred as Universal Mobile Telecommunication System (UMTS). IMT-2000 will provide a multitude of services, especially multimedia and high bit rate packet data. WCDMA and cdma2000 have emerged as the mainstream air interface solution for the third generation networks.

1.1 CDMA Concepts:

In CDMA each user is assigned a unique code sequence to encode its information-bearing signal. The receiver decodes a received signal after reception based on its apriori knowledge of the transmitted code sequence and recovers the original data. This is possible iff the cross-correlation between the codes of the desired user and the codes of the other users are small. Since the bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal, the encoding

process enlarges (spreads) the spectrum of the signal and is therefore also known as spread spectrum modulation. The resulting signal is called a spread spectrum signal and CDMA is often denoted as spread spectrum multiple access. Following figure explains various types of CDMA scheme:

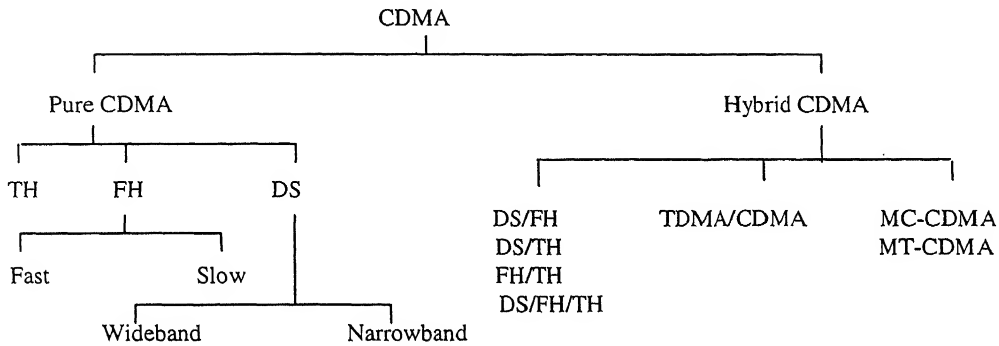


Fig 1.1: Various types of CDMA schemes

Let x(t) be the information bearing sequence defined as

$$x(t) = A.\sum_{n} x_n U(t - nT) \tag{1.1}$$

Where $\mathbf{x} = \{x_n\}$ is a source symbol sequence, A is the amplitude, and T is the symbol duration. PN sequence generator produces the following waveform

$$a(t) = \sum_{k} a_k h_a(t - kT_c) \tag{1.2}$$

Where $\mathbf{a} = \{a_k\}$ is the spreading sequence. T_c is the PN symbol or chip duration and $h_a(t)$ is the chip amplitude shaping function. This sequence after multiplication with

the original data sequence gives the spread sequence, known as spread spectrum signal y(t).

$$y(t) = A\sum_{n}\sum_{k=1}^{G} x_n a_{(nG+k)} h_a (t - (nG + k)T_c) \tag{1.3}$$

Where G is called the Processing Gain, defined as the ratio of the transmitted bandwidth (B_T) to the signal bandwidth (B_S) of the spread spectrum system.

$$G = B_T/B_S \tag{1.4}$$

The spectral spreading of the transmitted signal gives multiple access capability to CDMA. A spread spectrum modulation technique must fulfill two criteria:

- The transmitted bandwidth must be larger than the information bandwidth.
- The resulting radio-frequency bandwidth is determined by a function other than the information being sent (i.e., the resulting transmitting bandwidth is statistically independent of the information bandwidth).

The receiver correlates the received signal with a synchronously generated replica of the spreading code a(t) to recover the original information bearing signal. This implies that receiver must know the code used to modulate the data. Because of the coding and the resulting enlarged bandwidth, SS signals have a number of properties that are different from the properties of the narrowband signals.

1.2 Multiple Access Capability:

If multiple users transmit their signals simultaneously using spread spectrum technique, the receiver will still be able to distinguished between the users provided each transmitter uses a code which has sufficiently low cross-correlation with other codes. Correlating the received signal with a code signal from a certain user will then

only despread the signal of the user, while the other spread spectrum signal will remain spread over the whole bandwidth. Thus, within the information bandwidth the power of the desired user will be much larger than the interfering power (provided that not too many interferers are present) and the desired signal can be extracted. Following figure explains the signal power and bandwidth relation after (a) spreading and after (b) despreading, S and I indicate signal and interference respectively.

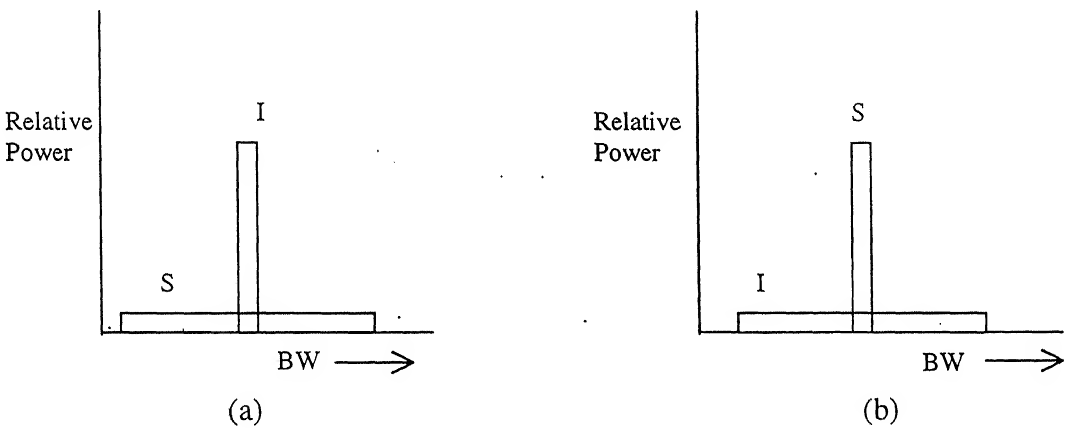


Fig 1.2: Interference rejection in CDMA (a) spreading (b) despreading

1.3 CDMA: Past, Present, and Future

The origins of application of the spread spectrum techniques are in the military field and navigational system. Such techniques, designed originally to counteract intentional jamming, have also proved suitable for communication through dispersive channel in cellular applications. For cellular applications Cooper

and Nettleton suggested CDMA in 1978. During the 1980s Qualcomm investigated DS-CDMA techniques, which finally led to the commercialization of cellular spread spectrum communication in the form of narrowband CDMA IS-95 standard in July 1993. Commercial operation of IS-95 started in 1996.

The decade of 1990s witnessed intensive studies of wideband CDMA techniques throughout the world with bandwidth of 5MHz or more. Several trial system have been built and tested. These includes FRAMES multiple access in Europe, core-A in Japan, the European/Japanese harmonized WCDMA scheme, cdma 2000 in the United States, and telecommunication technology association schemes in Korea. Based on these developments the CDMA era has been divided into three periods: the pioneer CDMA era, the narrowband CDMA era and the wideband CDMA era. Following section discusses wideband CDMA technology.

1.4 Air Interface Technologies for Third Generation:

In the search for most appropriate multiple access technology for third generation wireless systems, a number of new multiple access schemes have been proposed. These air interfaces are being developed by the standardization organizations in Europe, Japan, the United States and Korea. Fig 1.3 illustrates different schemes and their relation to the standard bodies and to each other.

Several Wideband CDMA proposals have been made for third generation wireless system. They are characterized by the following parameters:

- Provision of multirate services
- Packet data
- Complex spreading
- A coherent uplink using user dedicated pilot
- Additional pilot in the downlink for beamforcing
- Fast power control in the downlink

- Optional multiuser detection
- Seamless interfrequencey handover

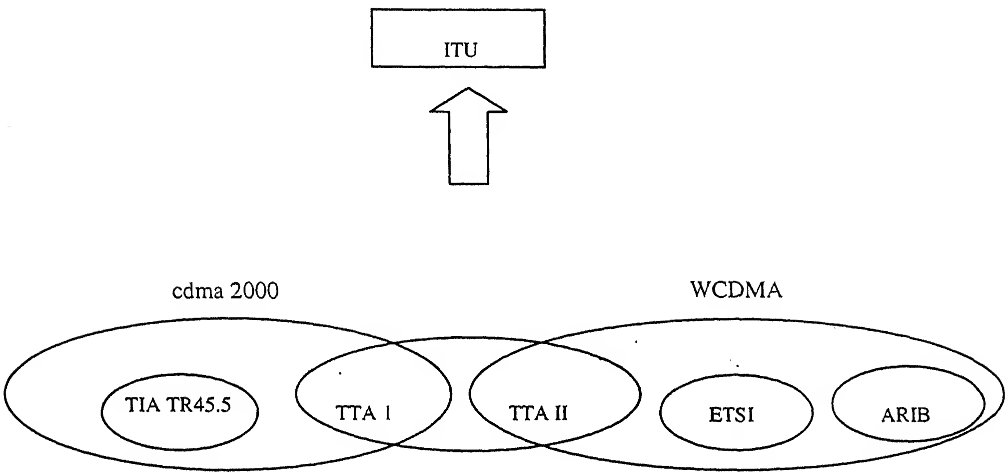


Fig. 1.3: Relationship between Wideband CDMA schemes and standard Bodies

WCDMA and cdma 2000 are the two most popular schemes. WCDMA is a network asynchronous scheme while cdma 2000 is network synchronous scheme like it's predecessor IS-95. In network asynchronous schemes the base stations are not synchronized using a common clock, while in the network synchronous schemes the base stations are synchronized to each other within a few microseconds. Following section presents a brief discussion on WCDMA.

1.4.1 WCDMA:

The WCDMA scheme has been developed mainly as a joint effort between ETSI (European Telecommunication Standard Institute) and ARIB (Association for Radio Industry and Business) as shown in fig. 1.3. Wideband CDMA has a bandwidth of 5MHz or more. Data rate of 144kbps and 384kbps are the main target of WCDMA and are achievable within 5MHz bandwidth with a reasonable capacity. Even 2Mbps peak rate can be provided under limited conditions. The bit rate targets have been specified according to the Integrated Services Digital Networks (ISDN) rates. The 144 kbps data rate provides the ISDN 2B+D channel, 384 kbps provides the ISDN H0 channel, and 2Mbps is similar to the ISDN H12 channel. However this thesis does not consider 2Mbps data rate for simulation. The 5MHz bandwidth can resolve (separate) more multipaths than narrower bandwidths, increasing diversity and thus improving performance. Larger bandwidths of 10,15 and 20MHz have also been proposed to support higher data rate more efficiently.

The following logical channels are defined for WCDMA:

- Broadcast control channel carries system and cell specific information
- Paging channel (PCH) for messages to the mobile in the paging area.
- Forward access channel (FACH) for messages from the base station to the mobile in one cell.
- Dedicated control channel (DCCH) covers the two dedicated control channel, stand alone dedicated control channel (SDCCH) and associated control channel (ACCH).
- Dedicated traffic channel (DTCH) for point to point data transmission in the uplink and downlink.

The WCDMA scheme employs long spreading codes. Different spreading codes are used for cell separation in the downlink and user separation in the uplink. In the

downlink, Gold codes of length 2^{18} are used, but they are truncated to form a cycle of 10 ms frame. The total number of available scrambling code is 5 12, divided into 32 codes group with 16 code in each group to facilitate fast cell search procedure. In the uplink either short or long spreading are used. For channelization, orthogonal codes are used. Orthogonality between the different spreading factor can be achieved by the tree-structured orthogonal codes. These codes preserve mutual orthogonality between different downlink physical channels even if they use different spreading factor.

Base stations in WCDMA need not to be synchronized, and therefore, no external source of synchronization, like GPS, is needed for the base station.

Following table summarizes WCDMA access scheme.

Table 1.1: WCDMA Parameter Summary

Channel Bandwidth	1.25,5,10,20 MHz
Downlink RF channel	Direct spread
Chip rate	1.024/4.096/8.192/16.384 Mc/s
Frame length	10ms/ 20ms (optional)
Spreading modulation	Balanced QPSK (downlink) Dual channel QPSK (uplink) Complex spreading circuit
Data modulation	QPSK (downlink) BPSK (uplink)
Coherent detection	User dedicated time multiplexed pilot (downlink and uplink)
Multirate	Variable spreading and multicode
Spreading factor	4-256

Power control	Open and fast closed loop(1.6KHz)
Spreading (uplink)	Variable length orthogonal Sequence for channel separation, Gold sequence 2^{41} for user separation (different time shifts in I and Q channel)
Spreading (downlink)	Variable length orthogonal sequence for channel separation Gold sequence 2^{18} for cell and user separation (truncated 10 ms cycle)
Handover	Soft handover Interfrequency handover

1.5 Future Requirements:

Future wide area cellular wireless networks will support a variety of services, like web traffic, file transfer etc besides voice traffic. The network will have to accommodate users of different applications, having time varying data rates or requiring different quality of service (QoS). A mobile terminal may be set up and modify session for voice, data and image, as well as video through wireless connections to the base station. In order to provide such services, the network must be able to statistically multiplex users of different rates and/or QOS requirements, while maximizing the spectral efficiency. Moreover the network should provide a fair capacity sharing among all busy users and allow peak capacity access by one

user if all other are idle. Thus, the attraction of packet based wireless service is evident. A technology that meets the above requirement and can evolve from emerging digital cellular system will be quite attractive as a basis for personal communication service.

1.6 Objective of this Thesis:

Until recently power allocation in the forward link of CDMA was not a big problem because of the low data rate traffic, mainly for voice services. But in the case of third generation CDMA, forward link analysis becomes very vital for system performs due to higher data rate services. One of the main aim of UTMS (Universal Mobile Telecommunication System) is to provide a data service like WWW browsing. Web traffic is mainly downlink (from base station to mobile) as the uplink (from mobile to base station) usually carries little traffic. Uplink data, for example, may just be a connection request to a web site. The required transmission power is in general proportional to the data rate and may be very high for the user located near cell boundary because of the propagation losses. For a system to support multiple user classes (data rates) a very efficient power allocation algorithm is required. Total transmitted power of base station is scarce and it should be used with a reasonable fairness to support all categories of traffic.

The objective of this thesis work is to study and simulate various resource allocation algorithms for multiservice wideband CDMA with parameters similar to WCDMA. These algorithms are running at the base station for forward link power allocation. Three types of user classes are assumed with data rate of 9.6kbps, 144kbps and 384kbps respectively. 9.6kbps traffic is primarily for voice, while higher bit rate channels are for data traffic only. It is natural to assume that the traffic is bursty, which is true for web traffic and file transfer. A mix of dynamic and static algorithms

is proposed, under the constraint that the base stations is total transmitted power limited, and their relative performance is compared.

1.7 Literature Survey:

Considerable work has been done over the years in the field of CDMA. Many proposals have been made for high data rate application over CDMA access networks [2], [3], [4]. [5] has explained a load and interference based scheme for supporting high data rate packet communication. These kinds of proposals are now being standardized in the revision B of IS-95. After the standardization of the IMT-2000 proposals, several recent papers, e.g. [10], [11] and [17], are devoted to wideband technology. Problem of resource allocation for high data rate have been addressed in [6], [9]. We have followed the approach of [1], [5] and [6] for the interference analysis at the mobile station.

1.8 Layout of the Thesis:

This section gives a brief organization of this thesis. Chapter 2 discusses interference at the user side in a typical CDMA access scheme. Same cell and other cell interference analysis have been presented and mathematical base for the power requirement is described. Chapter 3 discusses various power allocation algorithms in the forward link of Wideband CDMA. We present the simulation model in Chapter 4. Chapter 5 presents results and relative performance of algorithms. Finally chapter 6 focuses on the conclusion and future scope in this field.

Chapter 2

Interference Analysis and Power Allocation

The main difference between CDMA and TDMA/FDMA coverage prediction is that in case of CDMA the interference estimation is crucial. Capacity in TDMA is limited by the time slots, and in FDMA it is limited by the bandwidth, while in CDMA capacity is limited by the interference. In other words, number of channels in the CDMA is not fixed, as is the case with TDMA/FDMA systems, and is dependent on the interference condition of the cell. Thus interference profile of an MS becomes an important criterion for system performance.

2.1 Downlink Interference Study:

Signal quality in the downlink can be measured by received E_b/N_0. Interference influences the received signal and has different values in the downlink and the uplink. In the uplink interference comes from various mobile users scattered in the home cell and in the adjacent cells, while in the downlink interference come from few but strong sources (base stations). As the interference experienced by a mobile depends on the path losses of various base stations to mobile, all the MS receive different interference levels depending on their location in the cell. It should also be noted that due to the downlink common channel transmission, the interference level is high even if the cell load is low. Figure 2.1 illustrate various source of interference for a mobile station (MS), considering only first tier of neighbouring cells. Base stations are situated at the center of the cell. Received power from home base station (A), shown by the bold line, consist of signal as well as interference power while signal power

received from other base stations, shown by dotted line, consist of only interference.

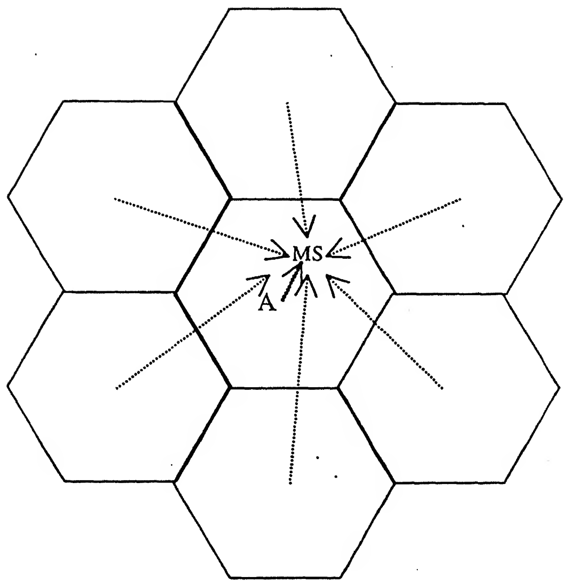


Fig 2.1: Forward link interference at the MS

Downlink interference can be classified into following two categories:

2.1.1 Same Cell Interference:

Ideally there is no same cell interference because of the use of orthogonal codes in CDMA forward link. But downlink is not perfectly orthogonal due to multipath propagation. Signals received at the MS come from various multipaths, which are shifted in time by different delays and their mutual orthogonality is destroyed to some extent.

Suppose that $I_{0,f}$ is the total received spectral density at the mobile station due to home base station including thermal noise and interference from various multipaths. Let the relative power of the kth multipath signal component be denoted by β_k, where $0 \leq \beta_k \leq 1$. That is, the portion of $I_{0,f}$ due to k^{th} path is

$$I_{0,k} = \text{spectral density for path } k = \beta_k I_{0,k}$$

Assuming that there are K multipaths at the receiving site, we have

$$I_{0,f} = \sum_{k=1}^{K} I_{0,k} = I_{0,f} \sum_{k=1}^{K} \beta_k \qquad \text{and} \quad \sum_{k=1}^{K} \beta_k = 1 \tag{2.1}$$

Suppose that at the mobile there are K receivers, each of which is set up to receive one of the K multipath. If E_{b0} is the total bit energy received from the base station for a particular forward link channel, then the bit energy input to the j^{th} receiver is

$$E_{bj} = \text{bit energy for path } j = \beta_j \, E_{b0} \tag{2.2}$$

The spectral density of the same cell interference to the j^{th} path, $I_{sc,j}$, is given by

$$I_{sc,j} = \sum_{k \neq j} I_{0,k} = I_{0,f} \sum_{k \neq j} \beta_k = I_{0,f}(1-\beta_j) \tag{2.3}$$

Thus the effective bit energy to noise plus interference density ratio at a demodulator that is set up to receive j^{th} multipath is

$$\frac{E_{bj}}{\left(N_{0,T}\right)_j} = \frac{E_{b0}\beta_j}{N_0 + I_{0.oc} + I_{0,f}(1-\beta_j)} \tag{2.4}$$

Where

N_0 = thermal noise power density

$I_{0,oc}$ = other cell cochannel interference spectral power density

$I_{0,f}$ = total same cell received spectral power density

$(N_{0,T})_j$ = total forward link noise plus interferenec density for path j

At the mobile receiver these multipaths are maximal ratio combined , and K most strong multipaths are chosen, i.e, the overall bit energy to interference density ratio is:

$$\frac{E_b}{(N_{0,T})} = \sum_{j=1}^{K} \frac{E_{bj}}{(N_{0,T})_j} = \sum_{j=1}^{K} \frac{E_{b0}\beta_j}{N_0 + I_{0,oc} + I_{0,f}(1-\beta_j)} \tag{2.5}$$

In equation 2.5 thermal noise has negligible effect as compare to other terms. For mobile close to the base station, the same cell cochannel interference dominates. Considering the effect of same cell interference only, we have

$$\frac{E_b}{(N_{0,T})} \approx \sum_{j=1}^{K} \frac{E_{b0}\,\beta_j}{I_{0,f}(1-\beta_j)} = \frac{E_{b0}}{I_{0,f}} \sum_{j=1}^{K} \frac{\beta_j}{1-\beta_j} = \frac{E_{b0}}{I_{0,sc}} \tag{2.6}$$

where $I_{0,sc}$ is the part of the total received same cell density $I_{0,f}$ that acts as interference. Thus the effective power density for the same cell cochannel interference can be defined as :

$$I_{0,sc} = I_{0,f} \div \sum_{j=1}^{K} \frac{\beta_j}{1-\beta_j} < I_{0,f} \tag{2.7}$$

Ratio of $I_{0,sc}$ to $I_{0,f}$ is called the orthogonality factor (α), defined as the fraction of total forward link received power which acts as the interference at the mobile station [6].

2.1.2 Other Cell Interference:

Signal received from other CDMA sectors and other CDMA cells' base stations also introduce interference to a mobile receiver. The interference power from other cell tends to fluctuate and can be modeled as lognormal random variable [1]. In other words the receive power from other base station in decibels is gaussian distributed.

Interference power(dbm)=average power(dbm)+Cons.(dB).Zero mean Gaussian R.V.

The average power from other cells can be calculated from path loss model. Path loss between mobile and base station is proportional to the γ^{th} power of the distance between them. γ is called the path loss exponent and is taken as 4 [5] for our simulation.

Fluctuation in the interference power from mean power is due to the shadowing effect. Shadowing are lognormally distributed and accounts for slow fading [14]. Hence the other cell interference can be modeled as lognormal random variable:

$$\begin{aligned} \text{Interference power} &= 10 \log_{10} I_i \\ &= 10 \log_{10} \bar{I}_i + \sigma_{dB}\, w_i \end{aligned} \tag{2.8}$$

Where w_i is a Gaussian random variable with zero mean and unit variance.

$\bar{I}_i$ depends on the path loss from base station to the MS and it is proportional to the distance between them.

Above equation can also be written as

$$\begin{aligned} I_i &= \bar{I}_i \times 10^{(\sigma_{dB} \cdot w_i)/10} \\ &= \text{Const.} \times \frac{1}{r_i^{\gamma}} \times 10^{(\sigma_{dB} \cdot w_i)/10} \end{aligned} \tag{2.9}$$

Where

$\bar{I}_i$ = median value of the interference power from base station i

r_i = distance from the mobile to the i th base station

γ = Propagation power law

$w_i \sim N(0,1)$

σ_{dB} is a standard deviation for the fluctuation and is in the range of 6-13 dB [5].

2.2 Base Station Transmit Power Calculation:

Let there be N number of user in the reference base stations BS_0 (home cell) and **p** is the transmitted power vector for the traffic user of various class.

$$\mathbf{p} = [p_1, p_2, \ldots\ldots\ldots\ldots p_N]$$

where p_i is the power transmitted for the i^{th} user.

Total downlink interference for the i^{th} user can be written as

$$I_{tot,i} = I_{intra,i} + I_{inter,i} \qquad (2.10)$$

Where $I_{intra,i}$ is the intracell interference and $I_{inter,i}$ is the intercell interference due to the interference power from neighbouring base stations. Total number of neighbouring base stations is M.

The total transmitted power for the home base station is

$$P_{tot,0} = \sum_{k=1}^{N} p_k \qquad (2.11)$$

Power received at the mobile station depends on its path loss to transmitting base station and also on the shadow fading parameter. Let $H = (h_{ij})_{1 \le i \le N,\ 1 \le j \le M}$ be the gain matrix as in [15], where the element h_{ij} accounts for the path loss between the i^{th} MS of home cell and j^{th} base station BS_j and is define as:

$$h_{ij} = \frac{A_{ij}}{d_{ij}^{\gamma}} \qquad (2.12)$$

Where A_{ij} models power variation due to shadowing and is a lognormally distributed random variable. All A_{ij} are assumed to be independent and identically distributed. d_{ij} is the distance between MS and BS_j. Path loss exponent (γ) is considered to be 4.

The intracell interference for MS_i connected to the BS_0 becomes:

$$I_{intra,i} = \alpha \sum_{\substack{k=1 \\ k \neq i}}^{N} p_k h_{i0} \qquad (2.13)$$

Where α is the orthogonality factor.

And the intercell interference is:

$$I_{inter,i} = \sum_{j=1}^{M} P_{tot,j} h_{ij} \qquad (2.14)$$

The received average bit energy to interference ratio in a multicell CDMA system with bandwidth W and the transmission rate of R_i can be written as[6]:

$$\frac{E_b}{N_0} = \varepsilon_i = \frac{W}{R_i} \cdot \frac{P_{req}}{I_{intra,i} + I_{inter,i}} \qquad (2.15)$$

Where (W / R_i) is the processing gain.

P_{req} is the required average power of the received signal at the MS.

In terms of the transmitted power for the i^{th} mobile station (P_i), above equation can be written as :

$$\varepsilon_i = \frac{W}{R_i} \cdot \frac{P_i . h_{i0}}{I_{intra,i} + I_{inter,i}}$$

$$= \frac{W}{R_i} \cdot \frac{P_i . h_{i0}}{\alpha \, h_{i0} . (P_{tot,0} - P_i) + \sum_{j=1}^{M} h_{ij} . P_{tot,j}} \qquad (2.16)$$

It gives:

$$P_i = \frac{\varepsilon_i \dfrac{R_i}{W}}{\left[1 + \dfrac{\alpha . \varepsilon_i . R_i}{W}\right]} \cdot \left[\alpha . P_{tot,0} + \frac{\sum_{j=1}^{M} h_{ij} . P_{tot,j}}{h_{i0}}\right] \qquad (2.17)$$

The number of user N connected to a base station is limited by it's maximum radiated power and must satisfy the following inequality:

$$\sum_j \nu_j . P_j \leq P_{max} \qquad (2.18)$$

Where P_{max} is the maximum permissible transmitted power by a base station and v_j is the activity factor associated with the j^{th} user. Base stations are considered to be total transmitted power limited for simulation analysis.

2.3 Average Transmitted power:

Power transmitted for a mobile user keeps on changing due to the movement of mobile and variation in the slow fading. The average required power for a traffic channel is inversely proportional to propagation loss from base station to mobile. Let P_r be the average traffic channel power for a mobile situated at a distance of r from the base station. P_r can be related to the power required for a user at the cell edge as:

$$P_r = P_R . \left(\frac{r}{R}\right)^{\gamma}; \qquad R = \text{cell radius} \qquad (2.19)$$

Assuming uniform density of the users in cell, the probability density function (pdf) of mobile distribution can be written as:

$$f_r = \left(\frac{1}{R}\right); \qquad 0 \le r \le R$$
$$= 0; \qquad \text{otherwise} \tag{2.20}$$

the average required forward link traffic power is

$$\overline{P} = \int_0^R P_r . f_r . dr$$
$$= P_R \int_0^R \left(\frac{r}{R}\right)^{\gamma} . \frac{1}{R} . dr \tag{2.21}$$
$$= P_R . \frac{1}{\gamma + 1} \tag{2.22}$$

Knowing P_R, average power of user can be calculated. Average power, thus calculated, is an important design consideration.

2.3.1 Rate Factor:

Average transmitted power for different classes of user is not same and it depends on the corresponding data rate. Let the average transmitted power for i^{th} class of user be $\overline{P}_i$. Considering voice to be the basic traffic type, average power transmitted for other class of user is equal to the average power required by voice traffic multiplied by a factor. Let us call this factor as the Rate factor and denote it by k_i for i^{th} class.

Where:

$$k_i = \left(\frac{\overline{P}_i}{\left(\overline{P}\right)_{voice}}\right) \tag{2.23}$$

Rate factor can be used to analyze performance of different type of traffic against a benchmark. We have used this factor to normalize traffic densities of different class of user to equivalent voice traffic.

Chapter 3

Power Allocation Algorithms

3.1 Algorithm1: Static Allocation with Power Reservation:

In this algorithm power at the base station is divided into three pools. Each power pool corresponds to a different class, that is, 9.6kbps (class 1), 144kbps (class 2) and 384kbps (class 3) class of data rate respectively. Call requests arrive at the base station where respective transmission power for individual calls is calculated. It is being assumed that base station acquires knowledge about the interference and fading conditions experienced by the mobile station through control channels. A check is made for the availability of required amount of power in the corresponding pool. If power is available for allocation that call is served, otherwise call is dropped and a blocking event is declared. Blocked call is immediately removed from the system. Due to the movement of mobile a call dropping / blocking may also occur if power balance becomes insufficient.

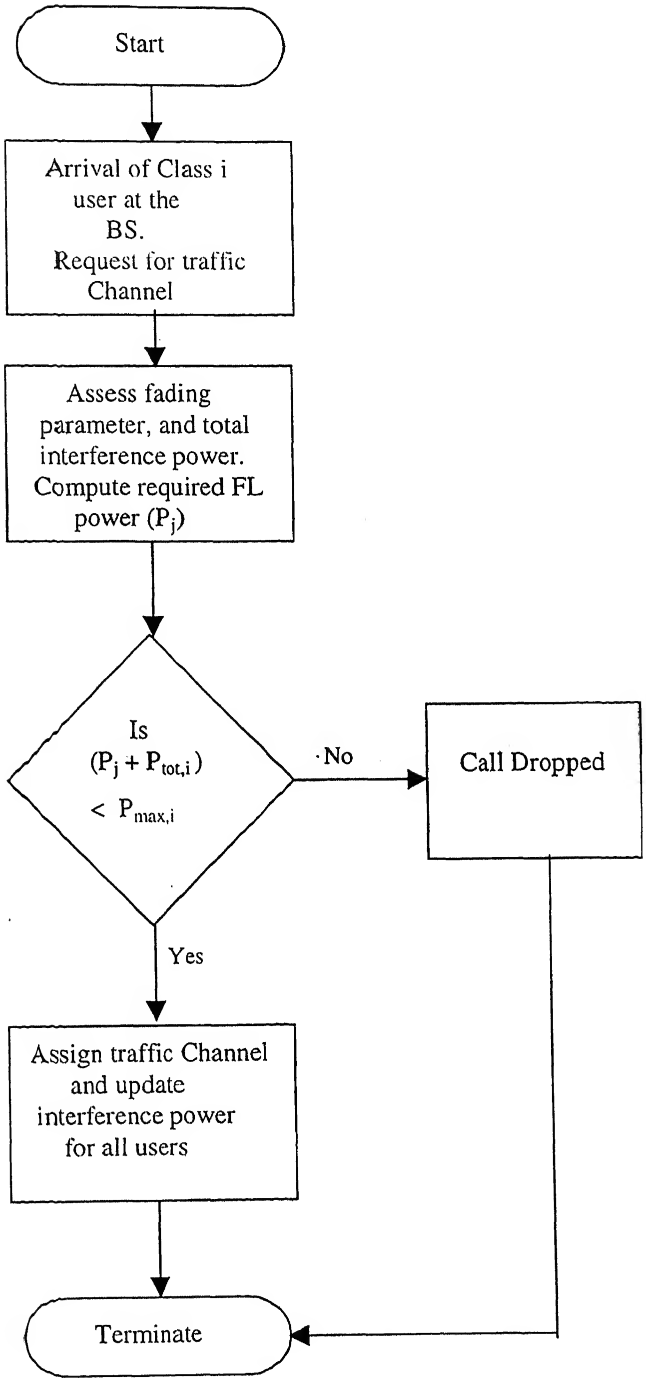
One of the important design criterion of this algorithm is the reservation of power for various classes so that the probability of blocking for each class is maintained within specified limits. Let ρ_i be the erlang load of i^{th} class of traffic where

$$\rho_i = \frac{\lambda_i}{\mu_i}$$

λ_i = poisson arrival rate for class i,

$1/\mu_i$ = average service time for i^{th} class

λ_i and μ_i depends on the traffic modeling and are different for voice and data. This is further explained in chapter 4.



FL: Forward Link

Fig 3.1: Flow diagram showing admission policy of only a single user for algorithm 1

Let $P_{tot,i}$ be the total available power for the i^{th} class. $P_{tot,i}$ is proportional to the load characteristic of the i^{th} class. That is:

$$P_{tot,i} \propto \rho_i$$

For same required E_b / N_0 at the mobile side, transmitted power is also proportional to it's bit rate and activity factor. Let k_i and v_i be the rate factor and activity factor respectively, associated with i^{th} class, then,

$$P_{tot,i} \propto k_i v_i \rho_i$$

Hence for i^{th} class of user a fraction ($k_i . \rho_i . v_i$) of total power is reserved. Power pool reserved for different classes can grow or shrink if any of these parameters changes. Since there is fair division of power between all classes, any particular user class can not capture most of the system resources. However, load of any user class has effect on total system interference because of common transmission bandwidth. Figure 3.1 shows user admission scheme for this algorithm.

3.2 Algorithm 2: Dynamic Allocation:

In dynamic algorithms no prior division of power is done for different class of users. Call requests arrive with Poisson rate. Power required for a user is computed, and a traffic channel is assigned if power is available otherwise the call request is dropped. This algorithm is robust in the sense that it does not require power division on the basis of the user traffic density of various classes, which is highly dependent on the user traffic characteristic of the cell region. For example, an area like IIT Kanpur may have a high data traffic requirement as compare to the voice traffic and for Kanpur city it could be the other way round. Capacity gain due to voice activity is shared by all user classes.

Disadvantage of this algorithm is in the case of increased data traffic, in which case data traffic will capture big share of system power, giving rise to more dropped voice calls. However a low blocking for data traffic at the cell radius is envisaged. User admission policy is similar to fig. 3.1 except that power is not divided among various user classes.

3.3 Algorithm 3: Dynamic allocation with data buffering:

In the two previous power allocation schemes high data rate user are found to be suffering from high blocking probability (refer to results). It is anticipated that in the future cellular networks, data traffic would surpass the voice traffic. We therefore need to evolve more efficient algorithm to improve performance for data users.

In this scheme we propose to exploit the delay tolerance nature, which is the property of most of the nonvoice source, by buffering data at the base station. Buffering is done only for nonreal time traffic (class 2 and 3 traffic).

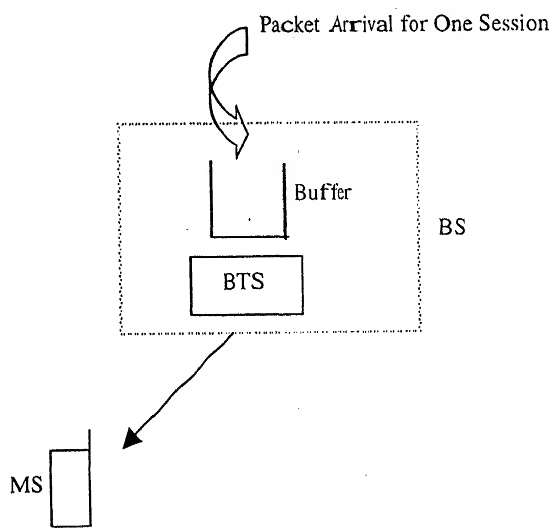


Fig 3.2: Scheme showing buffering of data at the Base Station

If there is not enough power available at the base station for allocation to the user, data packet of the user will be buffered at the base station. Base stations are assumed to be in contact with the mobile through control channels even when actual data transmission has not taken place. Separate buffers are maintained for each data transmission session as shown in fig. 3.2. When some power gets available to be allocation for forward link transmission, these buffered data packets are transmitted. New voice call is given precedence over backlogged data for the transmission. Lower bit rate data user, i.e. class 2, is given non preemptive priority over high rate user (class 3) for transmission of buffered data.

Buffering time is defined as the time during which the data packets for a mobile user are buffered at the base station due to the unavailability of resources. Buffer size is not a constraint for this algorithm and is considered to be infinite. Network does not put any limit on the buffering time. It is upto the user that how much time he wants to wait for service. Hence buffering time is modeled as exponentially distributed because of its resemblance with human nature.

Fig. 3.3 shows user admission policy for data burst at the base station.

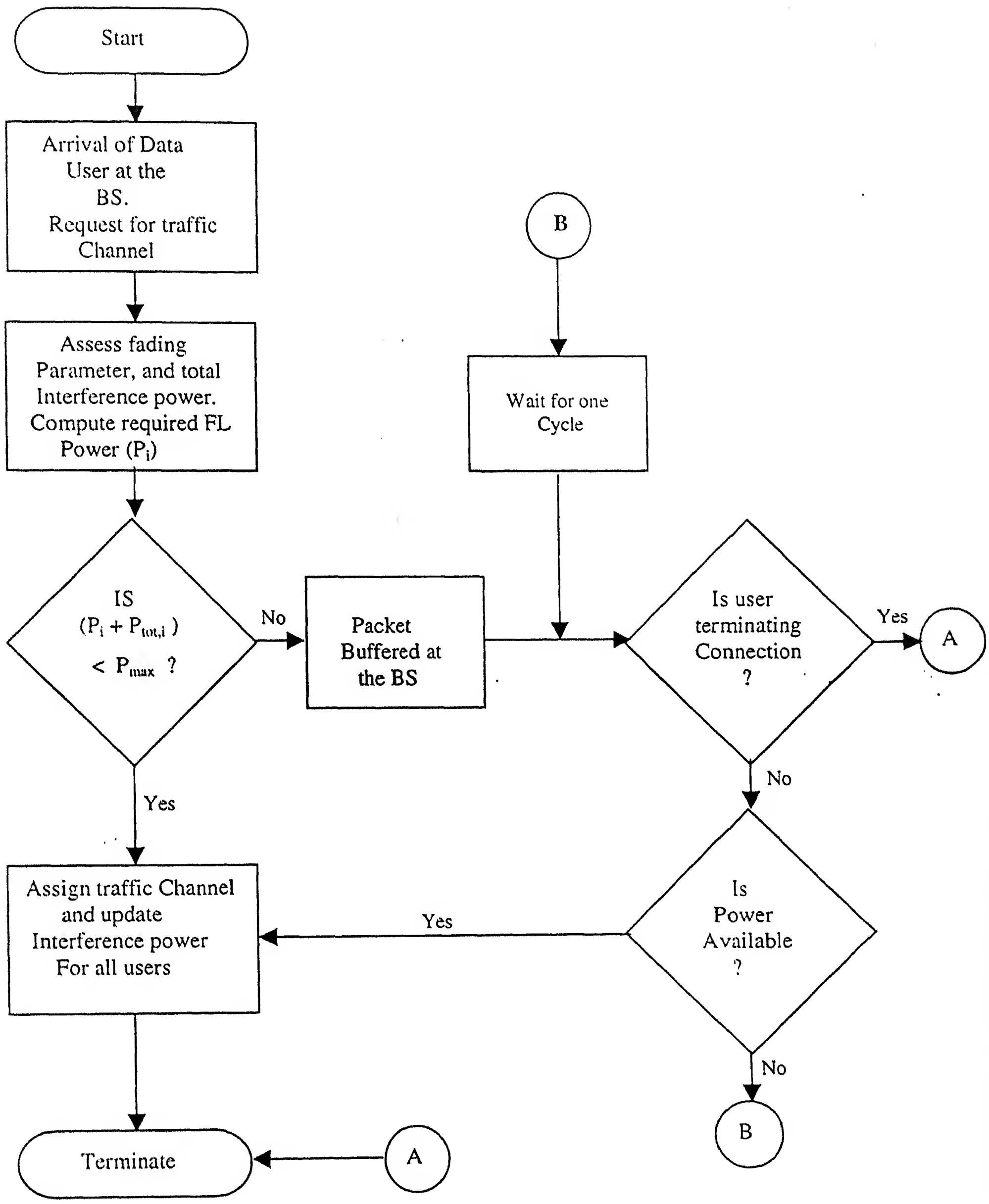


Fig 3.3: Flow diagram showing admission policy of a single data user for algorithm 3

Chapter 4

System Model Description:

4.1 Cell Structure:

In cellular technology like GSM the cell design is based on hexagonal cell structures. Analysis, as described by [16], however can also be done using circular cell geometry and has been considered for simulation in this thesis. The geometric technique called the concentric circle cellular geometry, considers all cells to have equal geographical area and specifies cell of interest to be a circular cell, located in the center of the surrounding cells. Interfering cells are wedge shaped and are arranged in the layers around the center cell of interest. Figure 4.1 illustrates the concentric circle geometry for a single layer of adjacent cells.

Let the center cell of interest have radius R. We assume mobile at a distance d_j, $d_j \leq R$, for j^{th} mobile. It is expected that the mobiles will be at least at a distance d_0 from the base station. Thus, $d_0 \leq d_j \leq R$ and d_0 is a very small distance as compare to the cell radius. Then, a first layer of adjacent interfering cell is found on $R \leq d_j \leq 3R$, a second layer is located on $3R \leq d_j \leq 5R$, and the i^{th} interfering layer is located on $(2i - 1) R \leq d_j \leq (2i + 1) R$. In each surrounding layer there are M_i adjacent cells, where i denotes the layer number. From geometry, total number of interfering equal area cells (area equal to the center cell) in the first layer comes out to be 8 and the angle span by each cell is 45^0. The concentric cell geometry is useful because location of a mobile user can easily be represented in polar coordinates (r, θ).

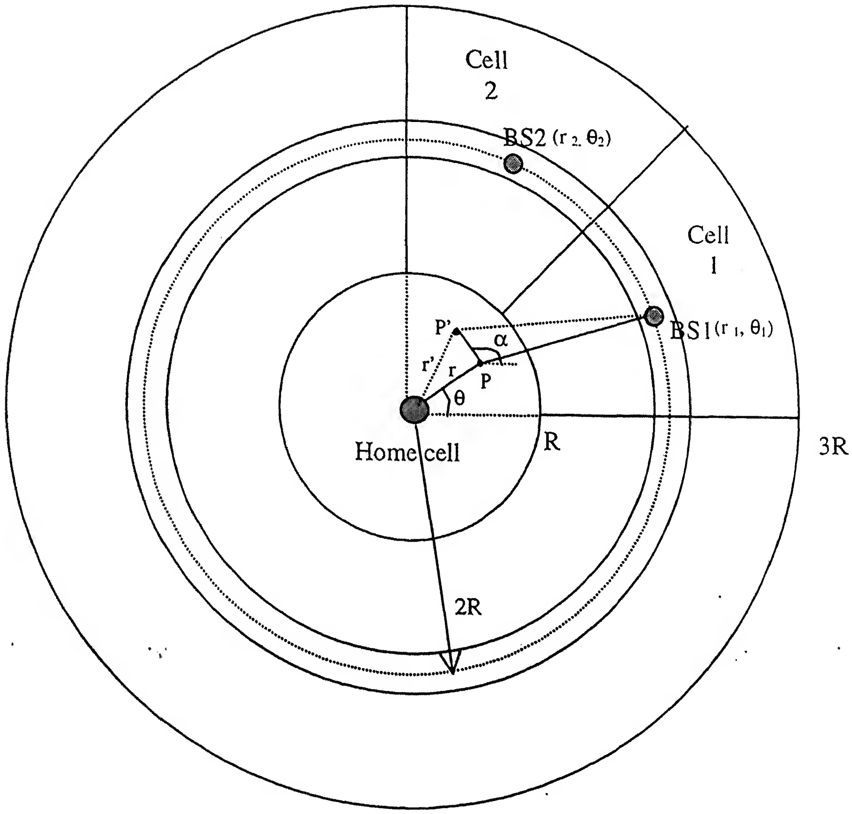


Fig 4.1: Equivalent cellular geometry

Let the home base station be at (0,0) location and the i^{th} neighbouring base station is located at (r_i, θ_i), considering the location of a specific user of home cell at (r , θ). Let the mobile be moving with velocity v and at an angle α from the horizontal axis. It's being assumed, for simplicity, that the direction of movement and velocity does not change during the course of service. Users are generated uniformly over the cell areas and moving in any direction with equal probability. User population is assumed to be infinite.

Distance of mobile from i^{th} base station is

$$d_i^{\,2} = (r.\text{Cos}\theta - r_i\,\text{Cos}\theta_i\,)^2 + \ (r.\text{Sin}\theta - r_i\,\text{Sin}\theta_i\,)^2 \qquad (4.1)$$

Distance covered by mobile in t sec. is equals to (v.t).

Now the new location of mobile after t second is

$$r' = \sqrt{r^2 + (vt)^2 + 2r.vt.\mathrm{Cos}(\theta - \alpha)} \tag{4.2}$$

And

$$\theta' = \tan^{-1}\left(\frac{r.\mathrm{Sin}\theta + vt.\mathrm{Sin}\alpha}{r.\mathrm{Cos}\theta + vt.\mathrm{Cos}\alpha}\right) \tag{4.3}$$

Again at this new location, distance of mobile from all the base stations can be calculated using equation 4.1.

If all the base stations transmit equal powers then, other cell received power to the same cell received power can be written as:

$$\left(\frac{I_{oc}}{I_{sc}}\right) = \frac{\sum_i d_i^{-4}}{r^{-4}} \tag{4.4}$$

Where, we assume the propagation path loss only. I_{oc}/I_{sc} is an important parameter and is used to determine cell size. Fig. 4.2 shows plot of (I_{oc}/I_{sc}), for the cell geometry shown in 4.1, as mobile moves in the central cell along a radial path towards the cell fringe.

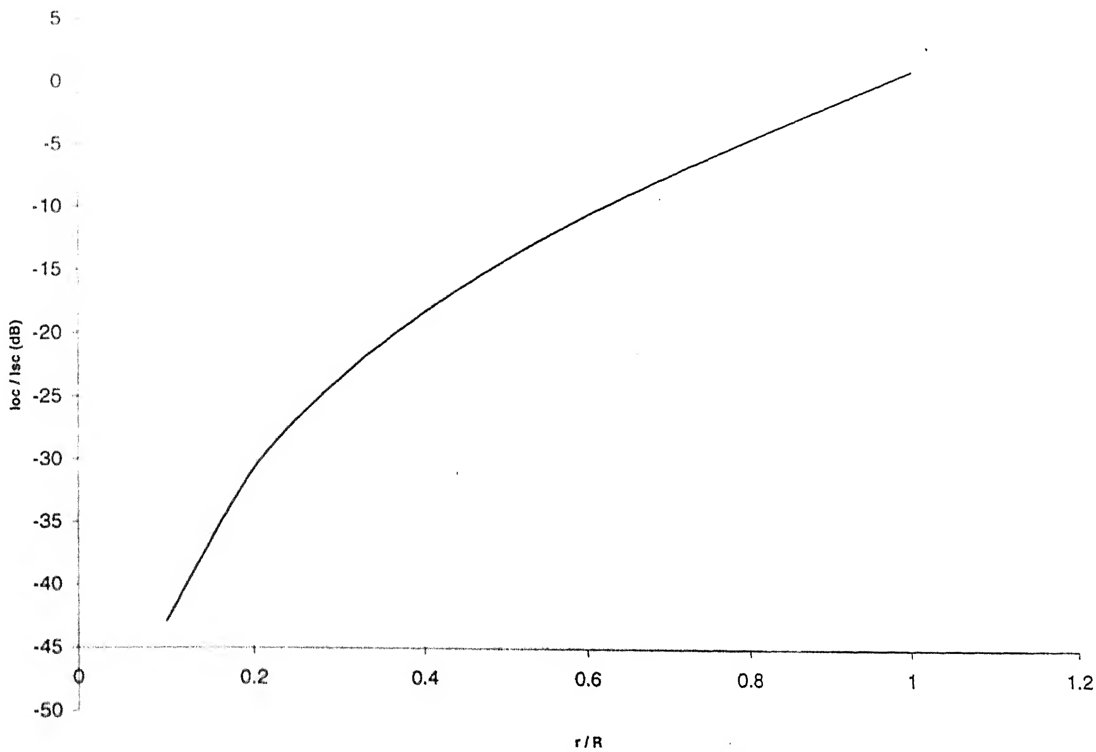


Fig 4.2: Interference profile of a mobile

4.2 Traffic model:

Three classes of user are considered in the system carrying data and voice information. Voice traffic is considered at 9.6 kbps and data traffic at 144 kbps and 384 kbps.

4.2.1 Voice traffic:

Arrival of voice calls at the base station is modeled as Poisson process. Interarrival time is exponentially distributed and is memoryless. Let λ_v be the call arrival rate then the probability of k arrival within a time span of t sec. is

$$P_r\{\text{ k arrival in } (0,t)\} = \frac{e^{-\lambda_v t}.(\lambda_v t)^k}{k!} \qquad (4.5)$$

Call duration is exponential distributed with mean μ_v and probability distribution function given by:

$$\mathrm{Pdf} = \mu_v . \exp(-\mu_v . t) \tag{4.6}$$

4.2.2 Data traffic:

The model of data traffic is considered for WWW browsing session. Sessions are generated according to Poisson distribution. Browsing session for a single user may require transmission of various data burst of variable packet length. Figure 4.3 illustrates a down link traffic scenario [17]. It is pointed out that traffic due to one specific session is modeled, not by the total flow from all the sessions. The following parameters define characteristics of the packet traffic:

- Session arrival process
- The number of packet bursts per session (N_{pc})
- The interarrival time between packet bursts (D_{pc}) , i.e., the reading time
- The number of packets in a packet buffer (N_d)
- The interarrival time between packets within a packet burst (D_d)
- The size of a packet (S_d)

The length of a session is modeled implicitly by the number of events during the session. Session arrival process defines how a session arrives to the base station. For each service there is a separate process.

N_{pc}, D_{pc}, N_d, and D_d are all modeled as geometrically distributed random variable with means μ_{Npc} (packets), μ_{Dpc} (seconds), μ_{Nd} (packets), and μ_{Dd} (seconds), respectively. Geometric distribution is a discrete representation of the exponential distribution. The geometric distribution for a random variable X with mean μ_x is defined by

$$P\{X=k\} = p(1-p)^k \qquad k=0,1,\ldots\ldots \qquad (4.7)$$

Where $p = \dfrac{1}{1+\mu_x}$

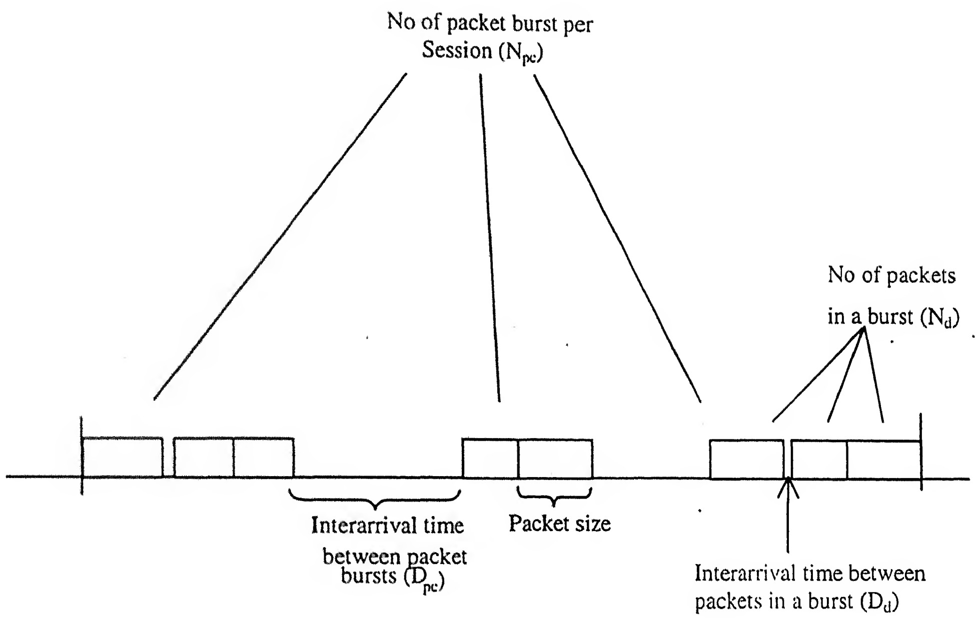


Fig 4.3: Data traffic during a typical WWW browsing session

According to [17] the packet size in WWW application can be modeled to follow Pareto distribution. The probability density function (pdf) of the Pareto distribution is defined as:

$$f_x(x) = \frac{\alpha . k^{\alpha}}{x^{\alpha+1}} \qquad \alpha, k \geq 0,\ x \geq k \qquad (4.8)$$

Average packet length is the mean of Pareto distribution, given by [appendix A]

$$\mu_x = \frac{k.\alpha}{\alpha - 1} \qquad \alpha > 1 \tag{4.9}$$

Table 4.1 [17] shows mean values for the various random parameter of a typical WWW service for mean packet size of 896 bytes:

Average no of bursts within a session	Average Reading time between bursts (sec)	Average no. of packets within a burst	Average interarrival time between Packets (s)	Average bit Rate (kbps)	Parameters for packet size distribution
5	12	15	0.05 0.02	144 384	k=81.5 α=1.1

Table 4.1: Typical parameters of WWW browsing model

Average data transmitted during a single browsing session

= (Avg. no of burst)$\times$ (Avg. no of packet in a single burst) $\times$(Avg. packet size)

= $5 \times 15 \times 896$

= 67.2 Kbytes (4.10)

Average service time for data channel is the time required to transmit the amount of data given by equation 4.10.

4.3 Design Approach:

Design approach of various algorithms are load and interference based. Power allocation on forward link is being done by examining power and interference constraint as explained in chapter 2. Equations 2.17 and 2.18 are reproduced here for convenience:

$$P_i = \frac{\varepsilon_i \frac{R_i}{W}}{\left[1+\frac{\alpha.\varepsilon_i R_i}{W}\right]} \cdot \left[\alpha.P_{tot,0} + \frac{\sum_{j=1}^{M} h_{ij}.P_{tot,j}}{h_{i0}}\right] \tag{4.11}$$

And

$$\sum_{j} v_j.P_j \leq P_{max} \tag{4.12}$$

Power transmitted for a user is proportional to its date rate as shown in fig 4.4. Spread spectrum bandwidth is 5 MHz. Received SNR (E_b/N_0) of 5 dB [8] is considered for all user classes.

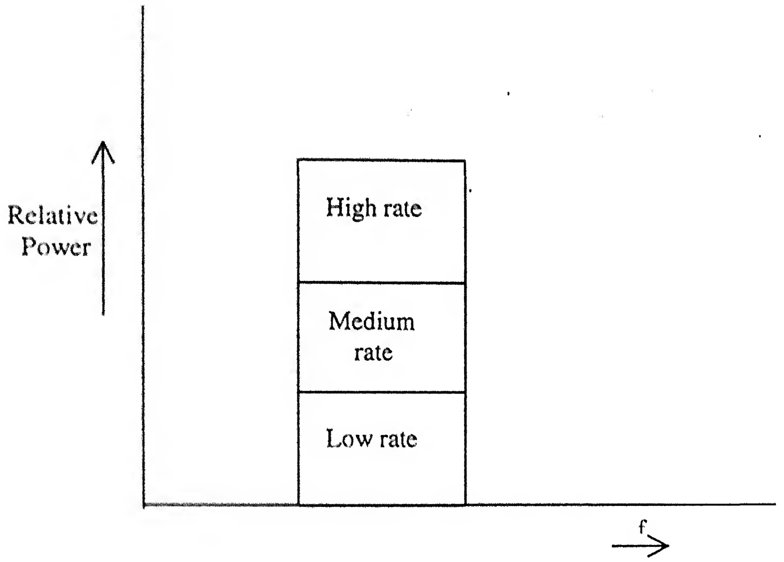


Fig. 4.4: Relative power of different data rate users

Orthogonality factor depends on many system parameters, like multipath channel characteristics, Rake receiver, transmission data rate, received SNR, etc. We have considered average orthogonality factor of 0.4 for each class of user [17].

Power control loop in the forward link is assumed to be running and transmitted power for a mobile is upgraded as it moves in the cell. If power required for a active user is

increasing and there is not enough power at the base station to meet its demand, received E_b/N_0 will fall below 5 dB. However, user is not dropped immediately, till its E_b/N_0 falls below 4 dB.

Voice activity of 0.4 is considered for voice traffic and no activity for data traffic.

4.3.1 Shadow Fading:

Shadow fading is caused by the presence of big obstacles, like hills, buildings, etc, in the line of sight between BS and MS. Due to shadowing effect, propagation path loss at the MS is not constant and can be modeled as a random variable. Empirical studies have proved that this random variation follows lognormal distribution [14]. Thus shadowing can be modeled as lognormally distributed.

The probability distribution function (pdf) of a lognormal random variable, X, can be defined as:

$$p(x) = \frac{2.\xi}{x.\sigma_{(dB)}\sqrt{2\pi}} \exp\left\{-\frac{\left(10\log_{10}x^2 - \mu_x\right)}{2\sigma^2_{(dB)}}\right\} \tag{4.13}$$

where $\xi = 10/\ln 10$

μ_x, and σ_{dB} denotes the mean and standard deviation (in dB) of X respectively.

It is being assumed that a user remains in same shadow fading condition throughout the call duration since it is slow fading. For data call this assumption is perfectly valid, because their burst duration is small while for voice call it is an approximation. Fig 4.5 Shows computer generated shadow fading distribution, for σ_{dB} equals to 8 dB, used for system simulation.

Table 4.2 summarizes system parameter used for analysis.

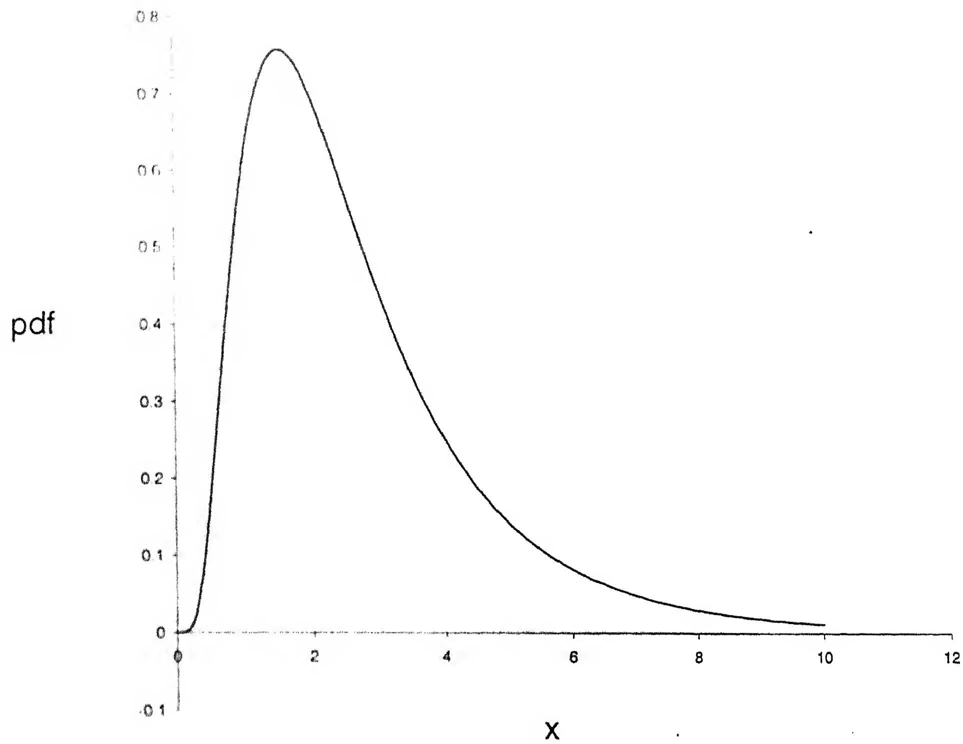


Fig. 4.5: Shadow fading distribution

Table 4.2: Summary of system parameters

Data Rates	9.6, 144, and 384 kbps
System Bandwidth	5 MHz
Orthogonality factor	0.4
Cell radius	1200 m
Propagation Loss model	CCIR
Shadowing Fading	8 dB Standard Deviation
Activity for voice, data	0.4, 1
Number of cells	9
Mobile Velocity	Uniformly Between (0-60) Km/s
User distribution	Uniform over the cell area
E_b / N_0 at the Receiver Side	5 dB for all Classes
Base Station Maximum Transmitted Power	4 Watt (only for data channels)
Handover	Hard
User movement direction	Uniformly 0-360°

Chapter 5

Results and Discussion

In this section, we present the results using the proposed algorithms and analyze the performance of the system in terms of the Probability of Blocking (POB), under different traffic densities. Results are based on simulation carried over of the different algorithms. System parameters are as shown in table 4.2.

Voice and data traffic is treated differently by each algorithm. Plots are drawn for each class of users under their varying Poisson arrival rates, while keeping other classes at a constant arrival rate. Since all the users share common resources, characteristics of one type of user have effect on the other classes. A combination of bar-line plot is being plotted to explain this effect for each class under each scheme.

In all graphs λ_1, λ_2, and λ_3 represents arrival rate for class 1 (voice at 9.6kbps), class 2 (data at 144kbps), and class 3 (data at 384kbps) respectively. For class 1, mean call holding time is considered to be 100 sec. and for data classes mean data length is 67.2 Kbytes. POB for voice traffic is the call blocking probability, while for data traffic it is the data burst blocking probability. Due to the large computational time required, we have not calculated the confidence interval.

5.1 Results For Algorithm 1:

From simulation, rate factor is calculated to be $k_1 = 1$, $k_2 = 14.5$, $k_3 = 36.5$.

In fig. 5.1 POB of voice traffic is shown against arrival rate λ_1. POB is very low, as expected, even at high call arrival rate. Variation in the value of λ_1 does not change POB of voice by noticeable amount because of the subsequent increment in the allocated power share. However, other classes are found to be suffering much, in term of POB, due to the increase in the share of voice traffic (fig. 5.2).

Fig 5.3 and 5.5 shows performance of this algorithm for data traffic of class 2 and 3 respectively. Data traffic needs higher transmission power and limiting them to their share of power only does not allow more data users in the system at a time, which gives rise to their POB. Fig. 5.4, and 5.6 show the effect of increasing λ_2 and λ_3 on the other classes respectively.

5.1.1 For Class 1 traffic:

Table 5.1: POB of class 1 vs λ_1 at different values of $[\lambda_2, \lambda_3]$

	POB for Class 1	
λ_1	$\lambda_2 = 0.25$ $\lambda_3 = 0.20$	$\lambda_2 = 0.30$ $\lambda_3 = 0.25$
0.1	0.00101	0.0012
0.2	0.00103	0.0016
0.3	0.00123	0.0022
0.4	0.00148	0.0027
0.5	0.00159	0.0029
0.6	0.00162	0.0031
0.7	0.00169	0.0033

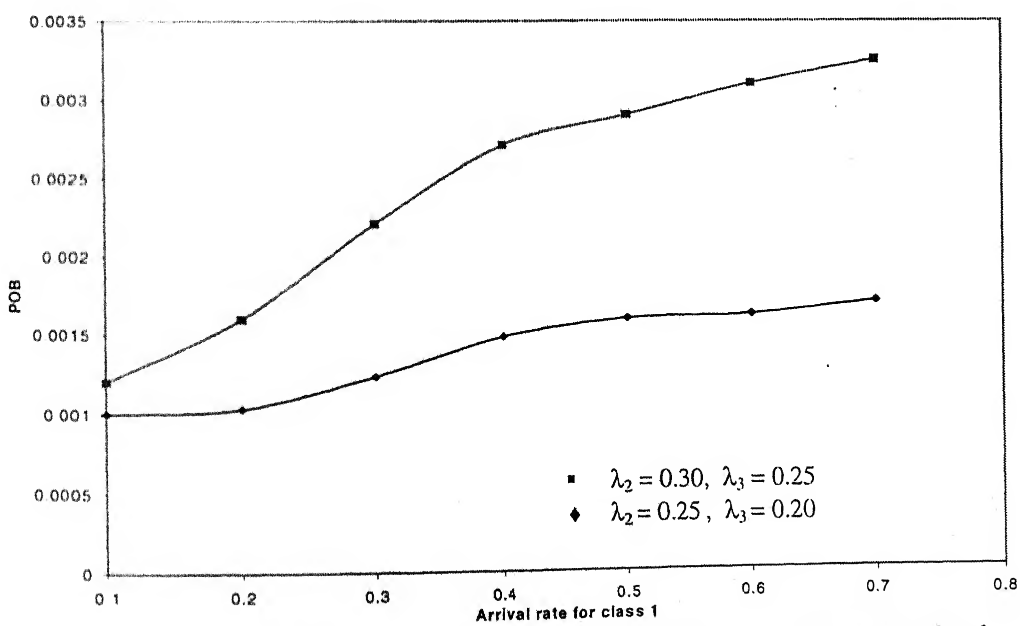


Fig. 5.1: Plot for table 5.1: POB of class 1 vs λ_1 at different values of $[\lambda_2, \lambda_3]$

Table 5.2: POB of all user classes on varying λ_1 only

λ_2=0.25, λ_3=0.20		POB		
Index	λ_1	Class 1	Class 2	Class 3
1	0.1	0.00101	0.114	0.351
2	0.2	0.00103	0.182	0.385
3	0.3	0.00123	0.322	0.477
4	0.4	0.00148	0.357	0.543
5	0.5	0.00159	0.386	0.563
6	0.6	0.00162	0.400	0.600
7	0.7	0.00169	0.501	0.676

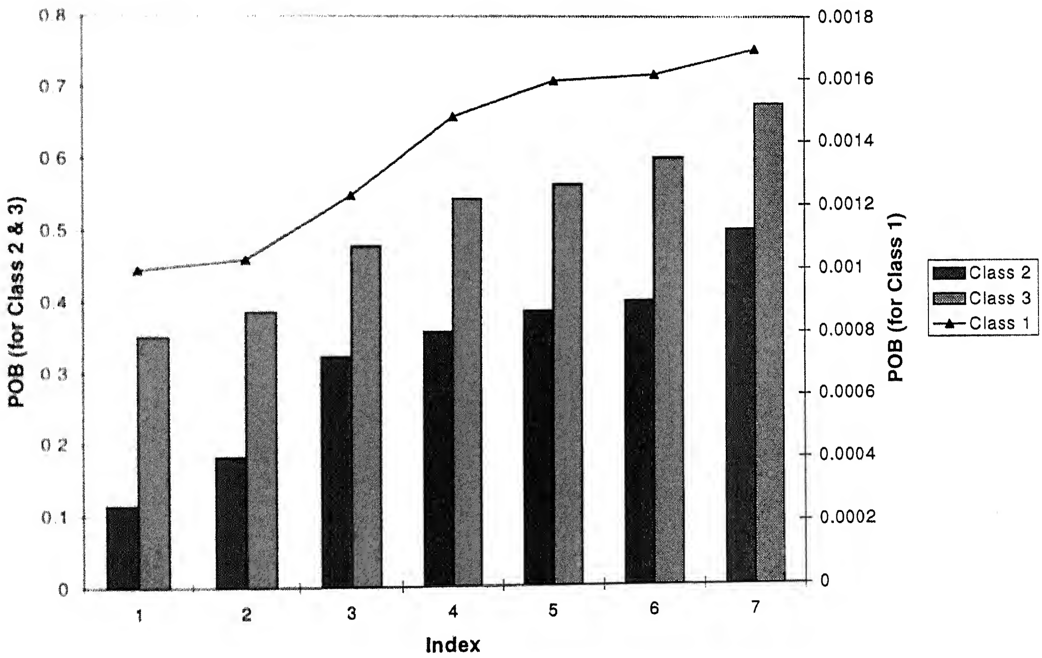


Fig. 5.2: Plot for Table 5.2: POB of all user classes on varying λ_1 only

5.1.2 For Class 2 Traffic:

Table 5.3: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

	POB for Class 2	
λ_2	$\lambda_1 = 0.40 \quad \lambda_3 = 0.15$	$\lambda_1 = 0.40 \quad \lambda_3 = 0.25$
0.1	0.204	0.311
0.2	0.293	0.344
0.3	0.311	0.377
0.4	0.383	0.463
0.5	0.495	0.529

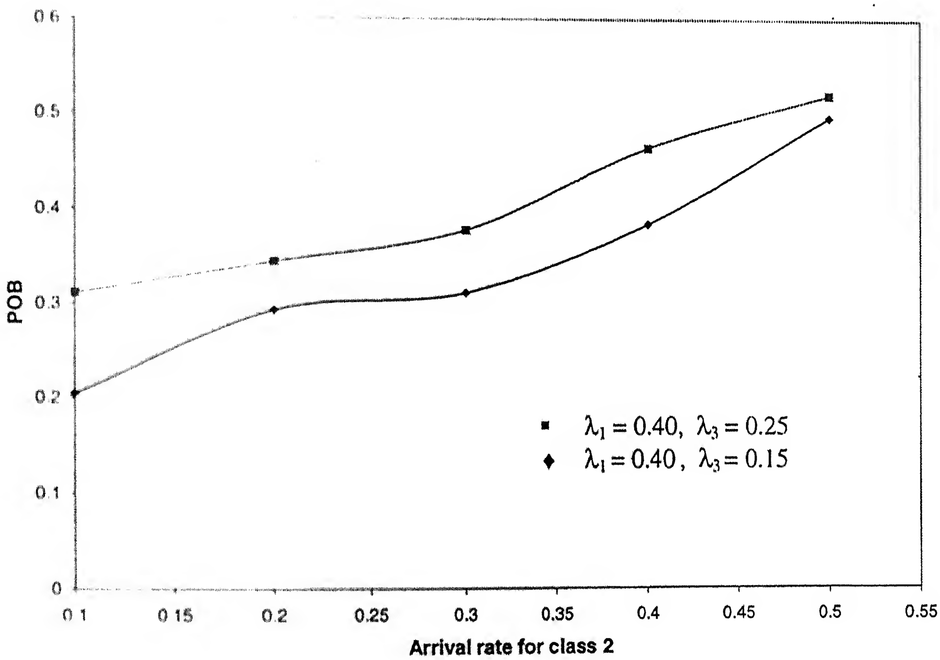


Fig. 5.3: Plot for Table 5.3: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

Table 5.4: POB of all user classes on varying λ_2 only

$\lambda_1=0.25$, $\lambda_3=0.20$		POB		
Index	λ_2	Class 1	Class 2	Class 3
1	0.1	0.00019	0.209	0.407
2	0.2	0.00023	0.293	0.418
3	0.3	0.00110	0.311	0.547
4	0.4	0.00170	0.383	0.625
5	0.5	0.00390	0.495	0.726

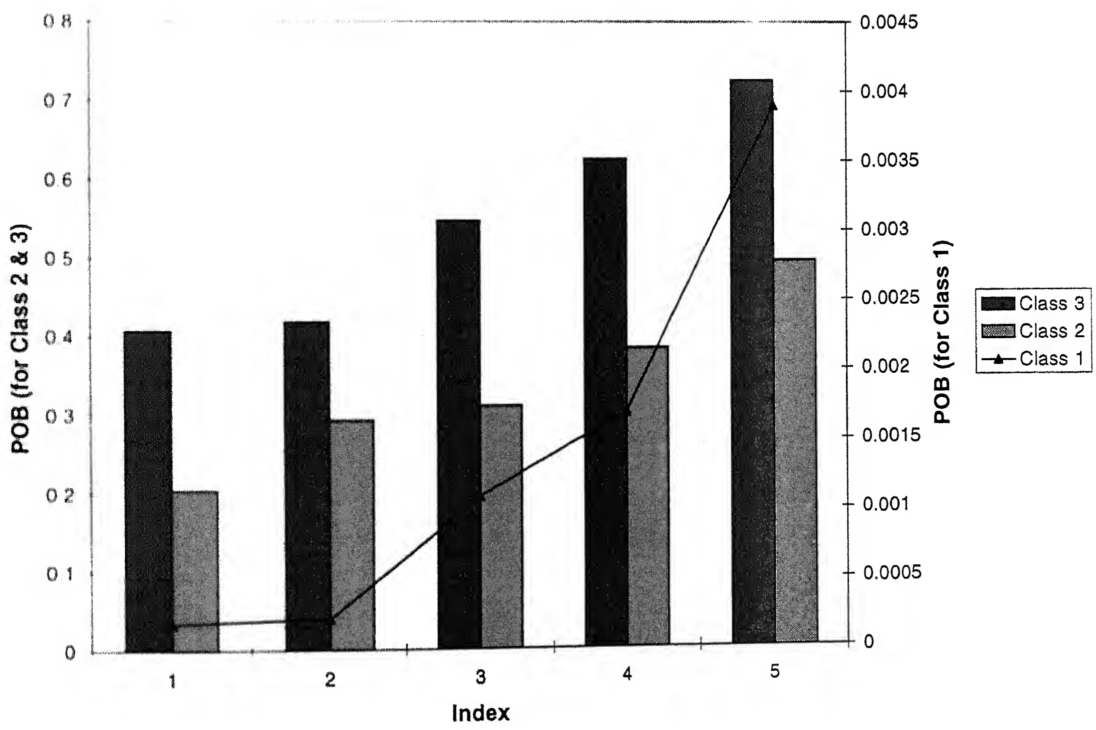


Fig. 5.4: Plot for Table 5.4: POB of all user classes on varying λ_2 only

5.1.3 For Class 3 Traffic:

Table 5.5: POB of class 3 vs λ_3 at different values of $[\lambda_1, \lambda_2]$

	POB for Class 3	
λ_3	$\lambda_1 = 0.40 \quad \lambda_2 = 0.20$	$\lambda_1 = 0.50 \quad \lambda_2 = 0.35$
0.1	0.381	0.555
0.2	0.459	0.602
0.3	0.511	0.639
0.4	0.546	0.669
0.5	0.587	0.679

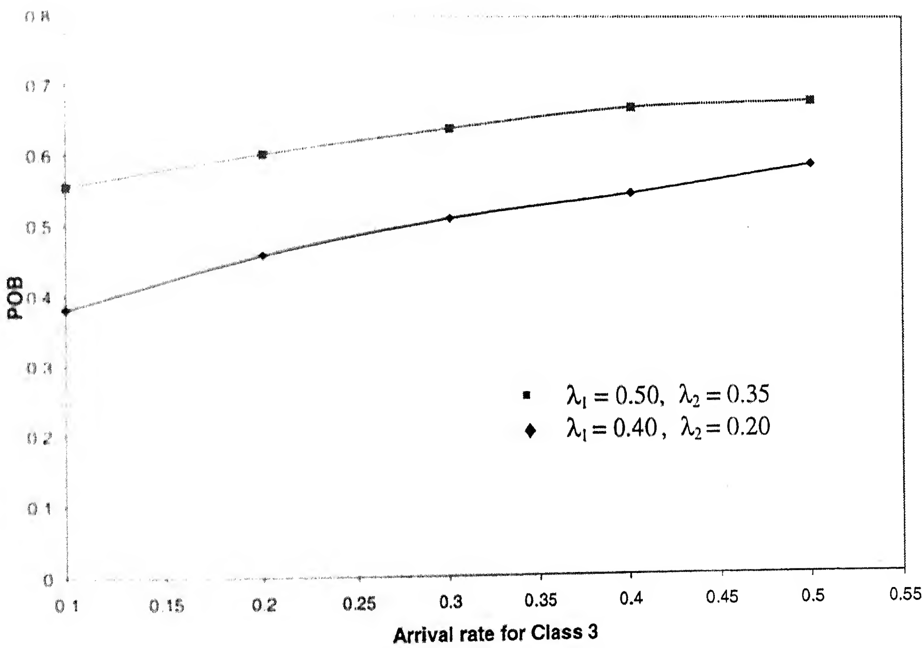


Fig. 5.5: Plot for Table 5.5: POB of class 3 vs λ_3 at different values of $[\lambda_1, \lambda_2]$

Table 5.6: POB of all user classes on varying λ_3 only

λ_1=0.40, λ_2=0.20		POB		
Index	λ_3	Class 1	Class 2	Class 3
1	0.1	0.0003	0.190	0.381
2	0.2	0.0009	0.333	0.459
3	0.3	0.0020	0.390	0.511
4	0.4	0.0036	0.491	0.546
5	0.5	0.0051	0.532	0.587

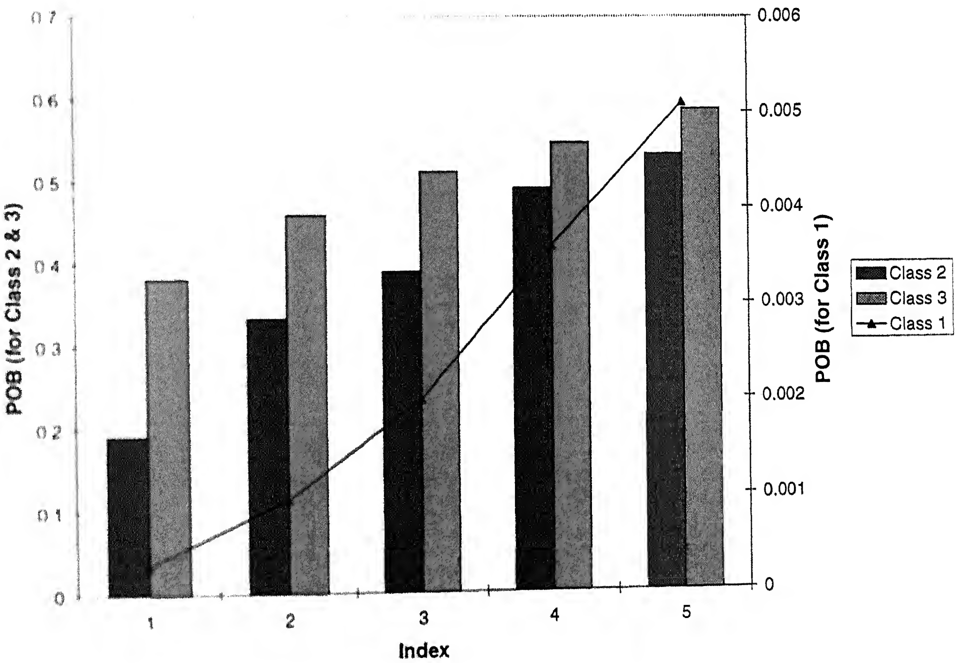


Fig. 5.6: Plot for Table 5.6: POB of all user classes on varying λ_3 only

5.2 Results for Algorithm 2:

In dynamic algorithm, performance of voice user is plotted in fig. 5.7 and fig. 5.8.
POB for voice is moderate and increases with the increase in λ_1. This algorithm offers a low POB for voice user and is feasible for high call arrival rate also.
POB of data classes is lower than the static algorithm. But at higher arrival rate (λ_2, λ_3) this algorithm is a poor performer. Reduction in the POB for data is at the cost of high POB for voice. Here increment in the user arrival rate of any class increases POB for all classes, as shown in fig 5.8, 5.10 and 5.12.

5.2.1 For Class 1Traffic:

Table 5.7: POB of class 1 vs λ_1 at different values of [λ_2, λ_3]

	POB for Class 1	
λ_1	$\lambda_2 = 0.25$ $\lambda_3 = 0.20$	$\lambda_2 = 0.30$ $\lambda_3 = 0.25$
0.10	0.0035	0.00943
0.20	0.0054	0.01427
0.30	0.0080	0.01137
0.40	0.0105	0.01575
0.50	0.0158	0.01793
0.60	0.0189	0.02210
0.70	0.0217	0.02898

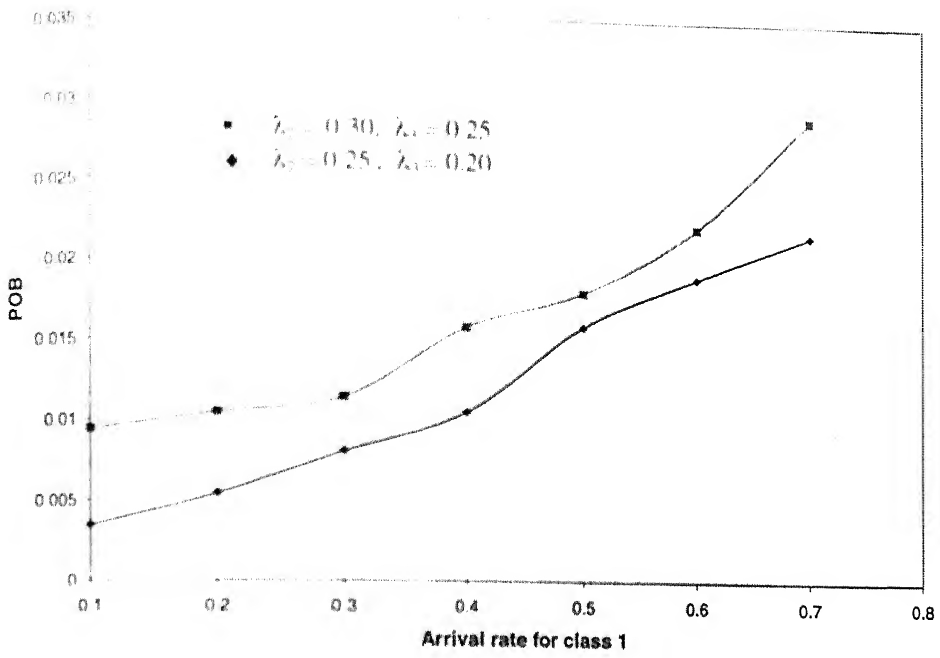


Fig. 5.7: Plot for Table 5.7: POB of class 1 vs λ_1 at different values of $[\lambda_2, \lambda_3]$

Table 5.8: POB of all user classes on varying λ_1 only

λ_2=0.25, λ_3=0.20		POB		
Index	λ_1	Class 1	Class 2	Class 3
1	0.10	0.00344	0.1455	0.278
2	0.20	0.00539	0.1920	0.352
3	0.30	0.00800	0.2060	0.382
4	0.40	0.01050	0.2260	0.417
5	0.50	0.01580	0.2950	0.475
6	0.60	0.01889	0.3370	0.546
7	0.70	0.02169	0.3690	0.578

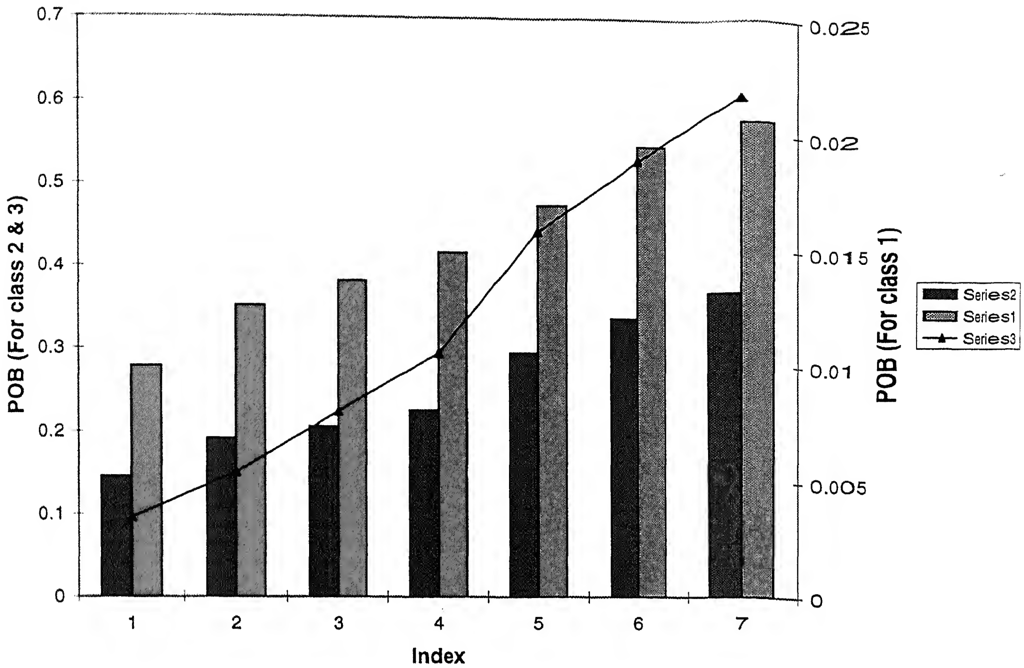


Fig. 5.8: Plot for Table 5.8: POB of all user classes on varying λ_1 only

5.2.2 For Class 2 Traffic:

Table 5.9: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

	POB for Class 2	
λ_2	$\lambda_1 = 0.40 \quad \lambda_3 = 0.15$	$\lambda_1 = 0.40 \quad \lambda_3 = 0.25$
0.10	0.0312	0.223
0.20	0.0385	0.241
0.30	0.2160	0.384
0.40	0.2970	0.407
0.50	0.3797	0.474
0.60	0.4730	0.496

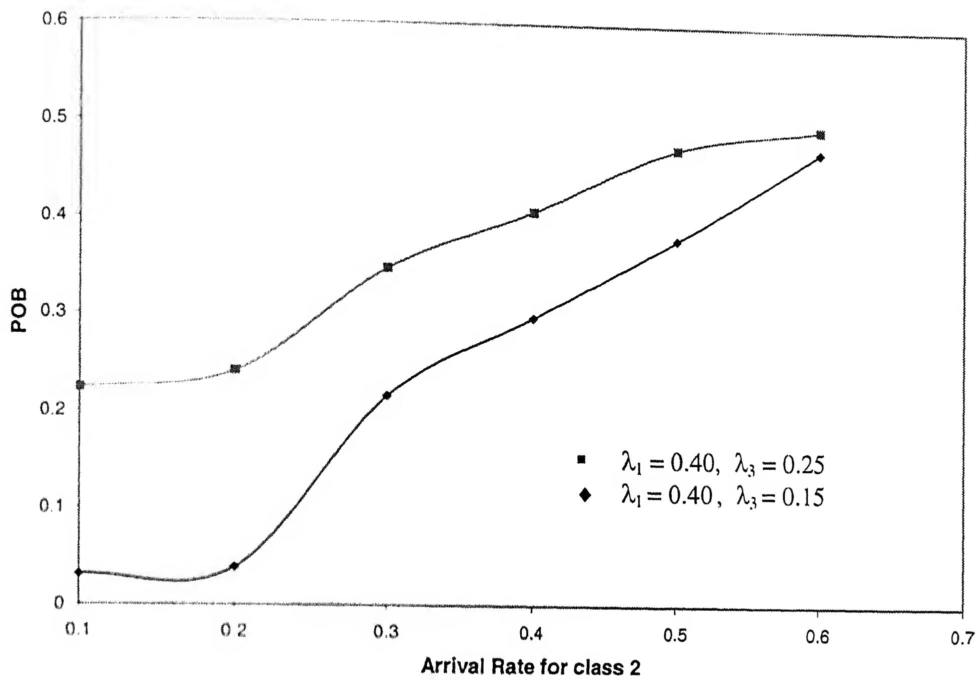


Fig. 5.9: Plot for Table 5.9: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

Table 10: POB of All User Classes on varying λ_2 only

λ_1=0.40, λ_3=0.15		POB		
Index	λ_2	Class 1	Class 2	Class 3
1	0.10	0.00074	0.0312	0.0913
2	0.20	0.00102	0.0385	0.1213
3	0.30	0.00713	0.2160	0.3693
4	0.40	0.01190	0.2970	0.4779
5	0.50	0.01766	0.3797	0.5820
6	0.60	0.02827	0.4730	0.6814

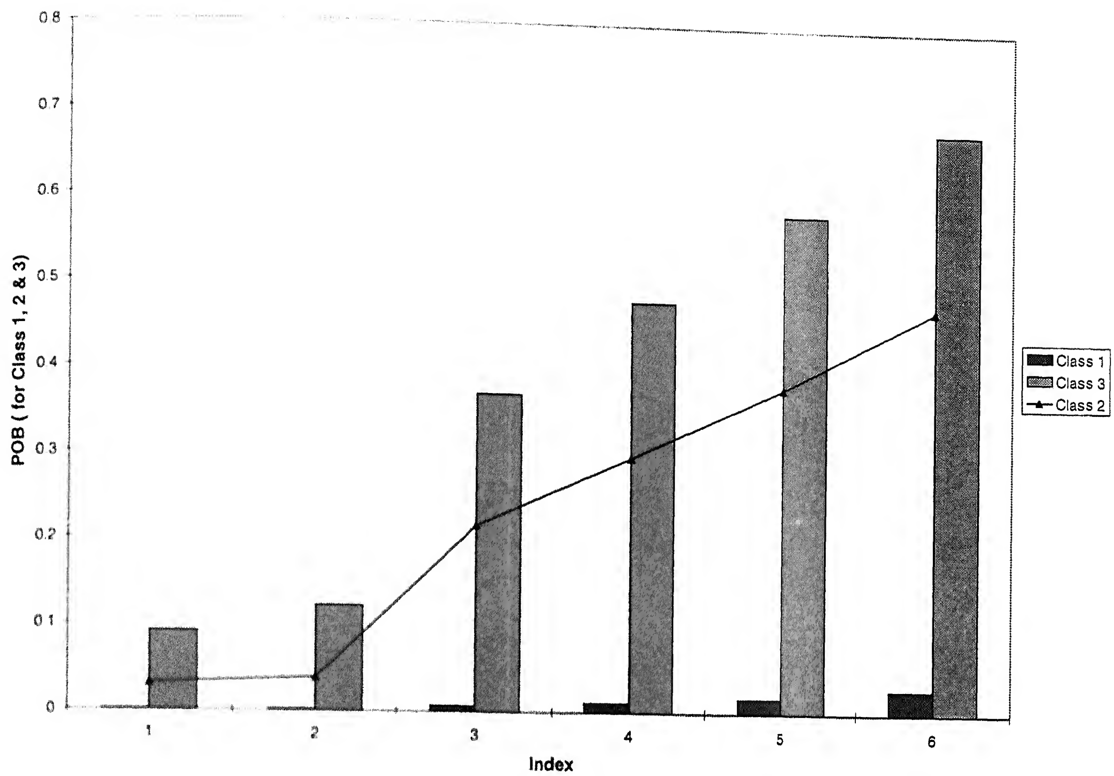


Fig. 5.10: Plot for Table 5.10: POB of all user classes on varying λ_2 only

5.2.3 For Class 3 Traffic:

Table 5.11: POB of class 3 vs λ_3 at different values of $[\lambda_1, \lambda_2]$

	POB for Class 3	
λ_3	$\lambda_1 = 0.40 \quad \lambda_2 = 0.20$	$\lambda_1 = 0.50 \quad \lambda_2 = 0.35$
0.10	0.209	0.547
0.20	0.414	0.600
0.30	0.494	0.670
0.40	0.565	0.701
0.50	0.610	0.711

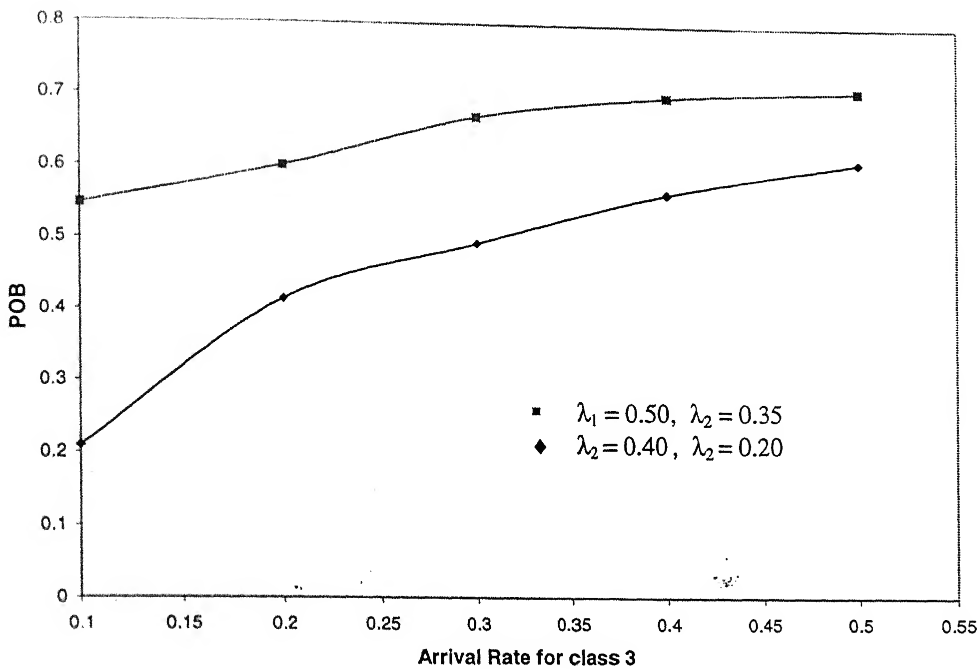


Fig. 5.11: Plot for Table 5.11: POB of class 3 vs λ_3 at different values of $[\lambda_1, \lambda_2]$

Table 5.12: POB of all user classes on varying λ_3 only

λ_1=0.40, λ_2=0.20		POB		
Index	λ_3	Class 1	Class 2	Class 3
1	0.10	0.0008	0.029	0.209
2	0.20	0.0098	0.229	0.414
3	0.30	0.0155	0.300	0.494
4	0.40	0.0130	0.363	0.565
5	0.50	0.0301	0.401	0.610

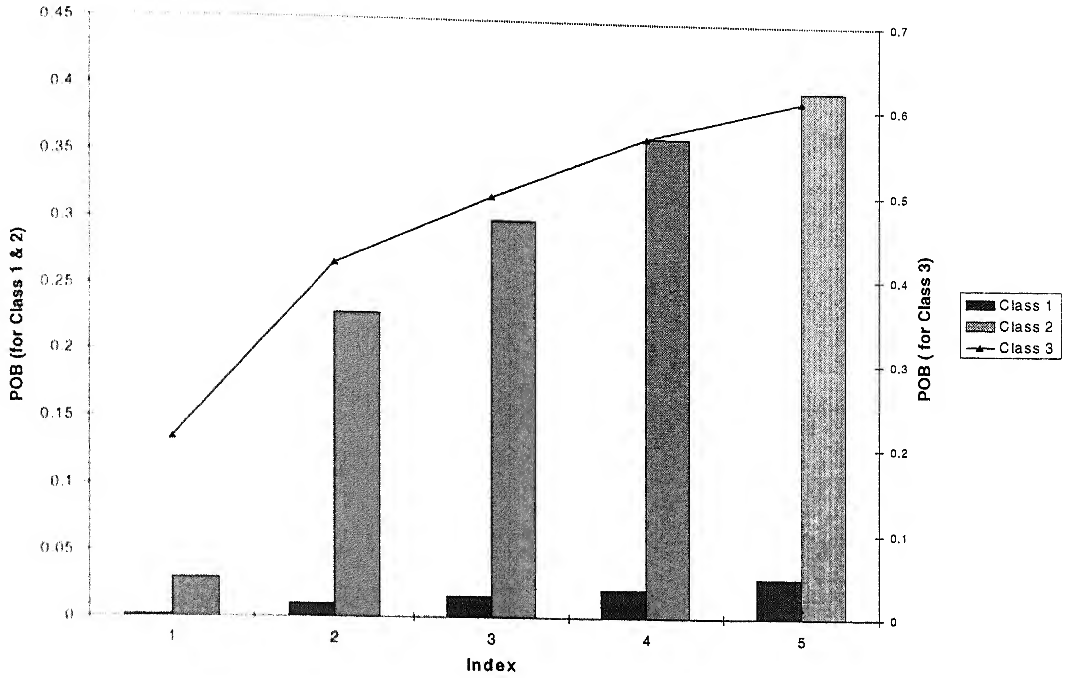


Fig. 5.12: Plot for Table 5.12: POB of all user classes on varying λ_3 only

5.3 Results For Algorithm 3:

Using buffers at the base station has an appreciable impact on the performance of data traffic. Since data traffic is bursty, its transmission time is small and they release resource (power) quickly, which allow allocation of channels for the buffered packets. Fig. 5.15 and 5.17 shows graph of POB vs arrival rate for class 2 and 3 respectively. Mean buffering time of 4 seconds is considered. There is a tradeoff between delay incurred by the system due to buffering and the POB. Buffering delay is a Quality of Service (QoS) parameter and can be set according to the user's need.

Beside good performance for data classes, voice traffic is found to be suffering with high POB as compared to the previous two schemes, as shown in fig. 5.13. This is caused due to the increase in the average number of data users, either active or buffered, in the system.

In this algorithm, like algorithm 2, increment in the arrival rate for any class increases POB for all classes, as shown by fig. 5.14, 5.16 and 5.18.

5.3.1 For Class 1Traffic:

Table 5.13: POB of class 1 vs λ_1 at different values of $[\lambda_2, \lambda_3]$

	POB for Class 1	
λ_1	$\lambda_2 = 0.25 \quad \lambda_3 = 0.20$	$\lambda_2 = 0.30 \quad \lambda_3 = 0.25$
0.10	0.0090	0.041
0.20	0.0117	0.101
0.30	0.0333	0.189
0.40	0.0941	0.260
0.50	0.2230	0.397
0.60	0.4250	0.463

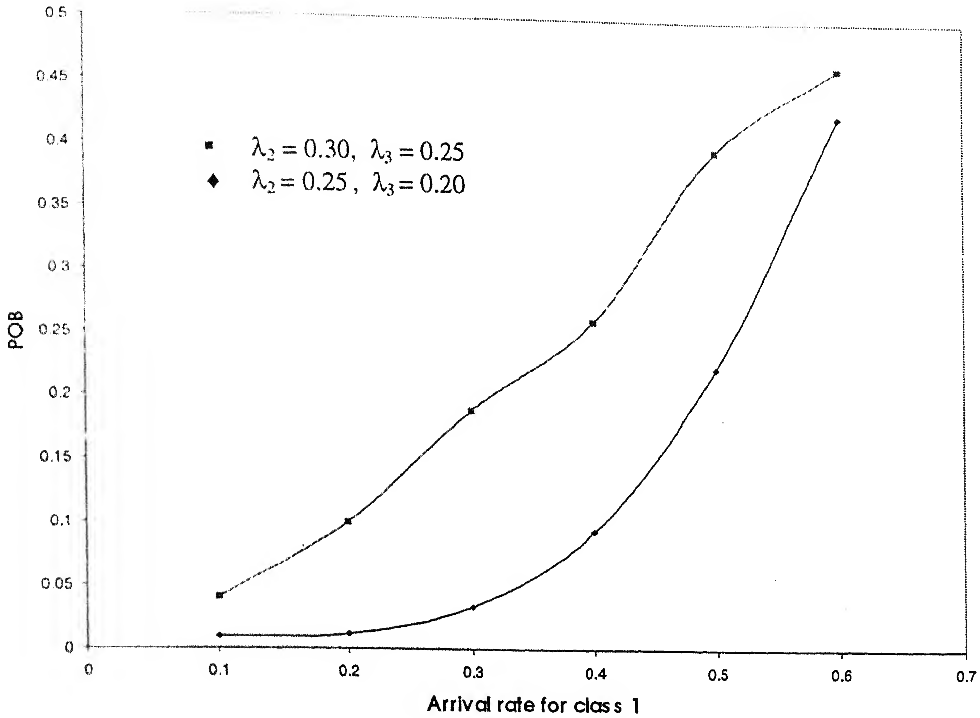


Fig. 5.13: Plot for Table 5.13: POB of class 1 vs λ_1 at different values of $[\lambda_2, \lambda_3]$

Table 5.14: POB of all user classes on varying λ_1 only

λ_2=0.25, λ_3=0.20		POB		
Index	λ_1	Class 1	Class 2	Class 3
1	0.10	0.0090	0.0009	0.00080
2	0.20	0.0117	0.0011	0.00134
3	0.30	0.0333	0.0030	0.00379
4	0.40	0.0941	0.0109	0.00992
5	0.50	0.2230	0.0220	0.02090
6	0.60	0.4250	0.1120	0.10950

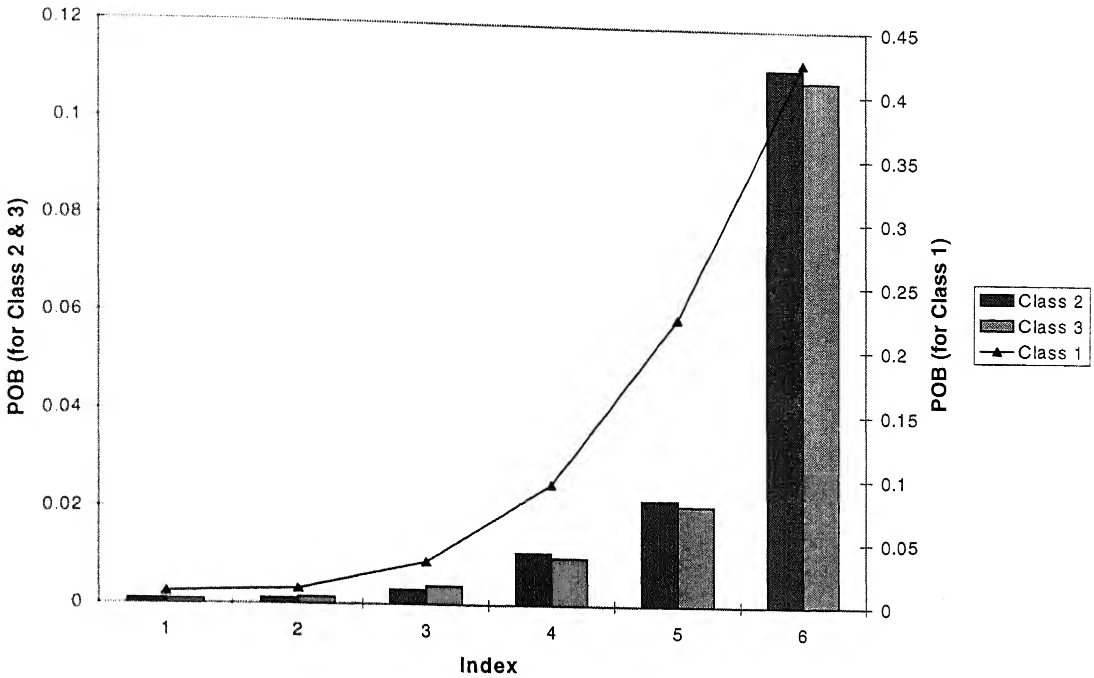


Fig. 5.14: Plot for Table 5.14: POB of all user classes on varying λ_1 only

5.3.2 For Class 2 Traffic:

Table 5.15: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

	POB for Class 2	
λ_2	$\lambda_1 = 0.40 \quad \lambda_3 = 0.20$	$\lambda_1 = 0.50 \quad \lambda_3 = 0.30$
0.10	0.00031	0.0098
0.20	0.00036	0.0520
0.30	0.01930	0.1030
0.40	0.06420	0.1101
0.50	0.07500	0.1140
0.60	0.09001	0.1520
0.70	0.10340	0.2001

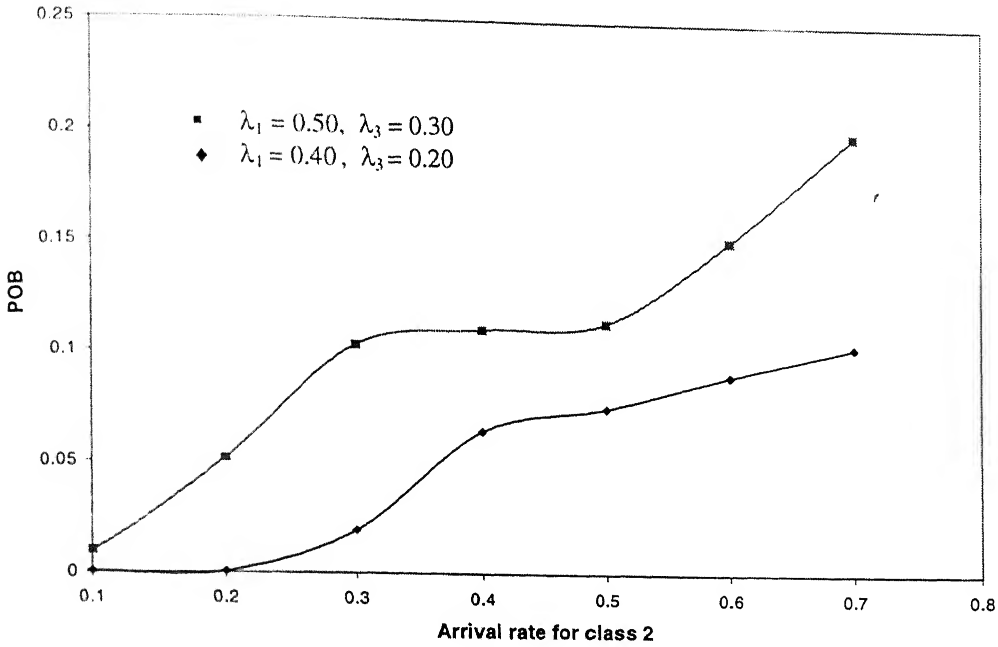


Fig. 5.15: Plot for Table 5.15: POB of class 2 vs λ_2 at different values of $[\lambda_1, \lambda_3]$

Table 5.16: POB of all user classes on varying λ_2 only

λ_1=0.40, λ_3=0.20		POB		
Index	λ_2	Class 1	Class 2	Class 3
1	0.10	0.0023	0.0003	0.00082
2	0.20	0.0038	0.0004	0.00084
3	0.30	0.1320	0.0193	0.01710
4	0.40	0.2770	0.0642	0.05840
5	0.50	0.2780	0.0750	0.05900
6	0.60	0.3600	0.0901	0.06120
7	0.70	0.3730	0.1034	0.10501

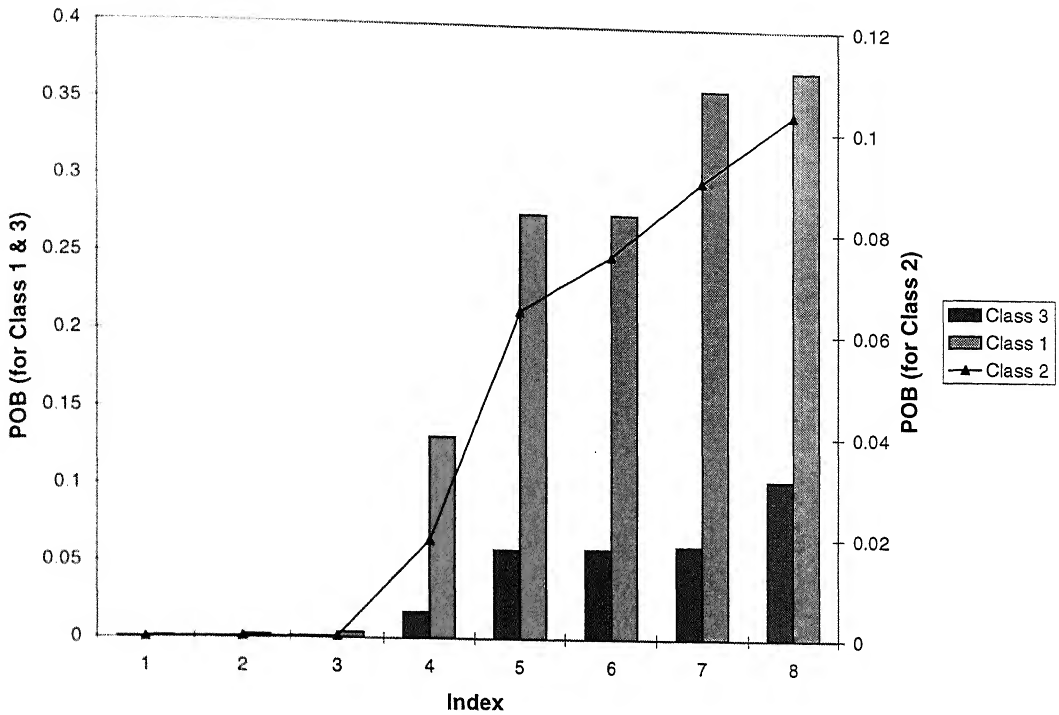


Fig. 5.16: Plot for Table 5.16: POB of all user classes on varying λ_2 only

5.3.3 For Class 3 Traffic:

Table 5.17: POB of class 3 vs λ_3 for different values of $[\lambda_1, \lambda_2]$

	POB for Class 3	
λ_3	$\lambda_1 = 0.40 \quad \lambda_2 = 0.20$	$\lambda_1 = 0.50 \quad \lambda_2 = 0.35$
0.10	0.0059	0.0128
0.20	0.0080	0.0210
0.30	0.0174	0.0587
0.40	0.0506	0.1740
0.50	0.1110	0.2100
0.60	0.1144	0.2590
0.70	0.1472	0.3001

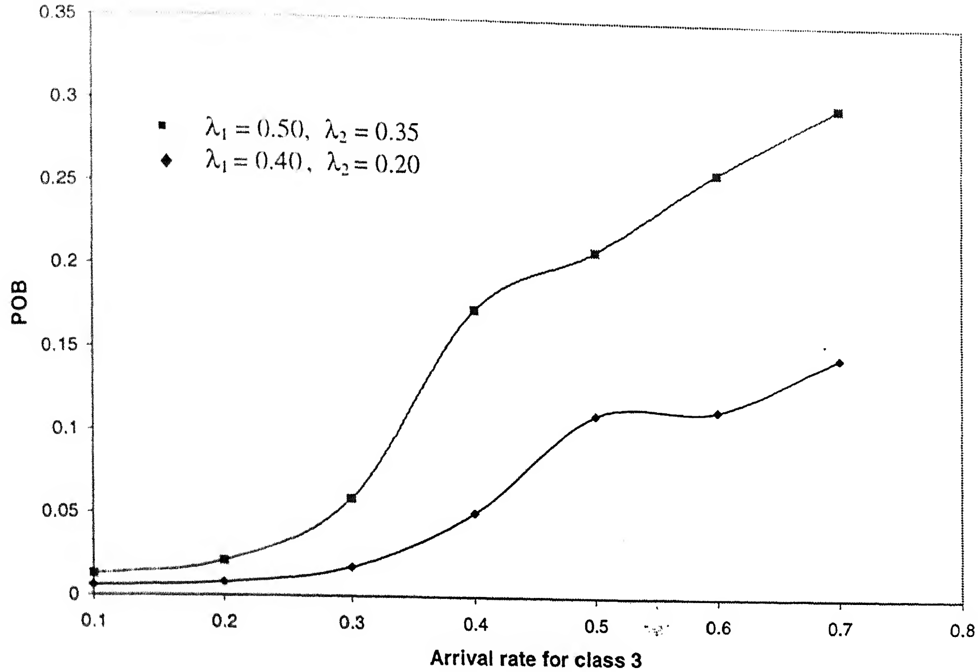


Fig. 5.17: Plot for Table 5.17: POB of class 3 vs λ_3 for different values of $[\lambda_1, \lambda_2]$

Table 5.18: POB of all user classes on varying λ_3 only

λ_1=0.40, λ_2=0.20		POB		
Index	λ_3	Class 1	Class 2	Class 3
1	0.10	0.0013	0.0004	0.0054
2	0.20	0.0479	0.0085	0.0080
3	0.30	0.2060	0.0157	0.0174
4	0.40	0.2680	0.0542	0.0506
5	0.50	0.4640	0.1090	0.1110
6	0.60	0.4840	0.1190	0.1140
7	0.70	0.5750	0.1540	0.1470

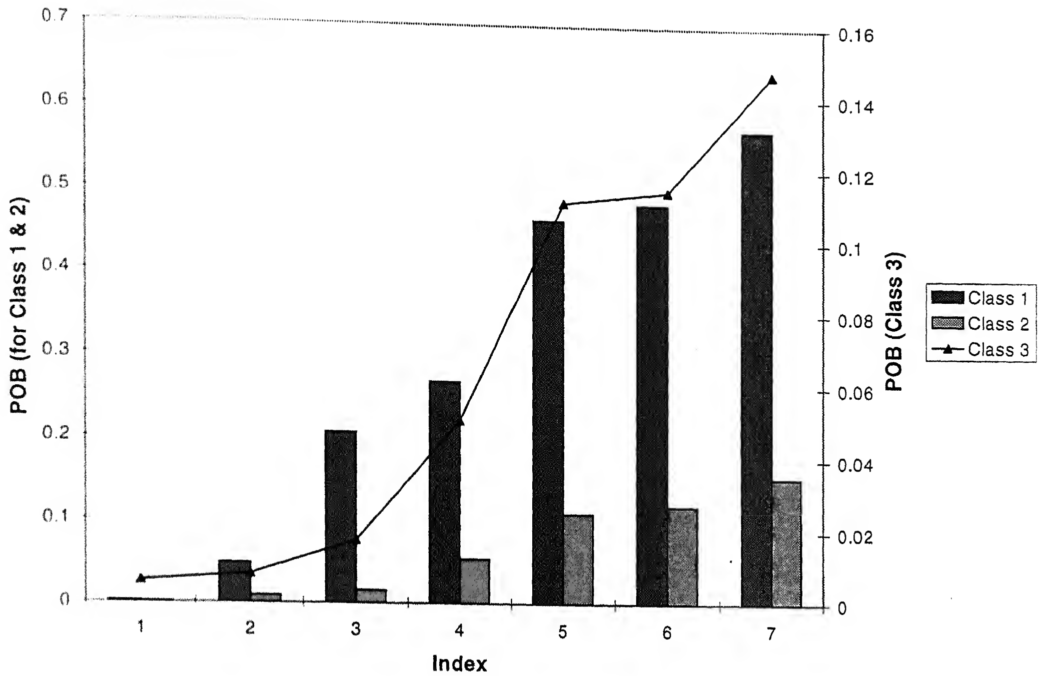


Fig. 5.18: Plot for Table 5.18: POB of all user classes on varying λ_3 only

5.4 Comparison:

To summarize all the algorithms for their relative performance curves have been drawn in this section. Fig. 5.19 compares the performance of all the three algorithms for voice traffic. For very low values of call arrival rate λ_1, algorithm 2 is offering lowest POB. But on increasing λ_1 POB is increasing rapidly. For algorithm 1, POB is almost constant and remains at a reasonable low value for all values of λ_1. Algorithm 3 is worse for voice traffic.

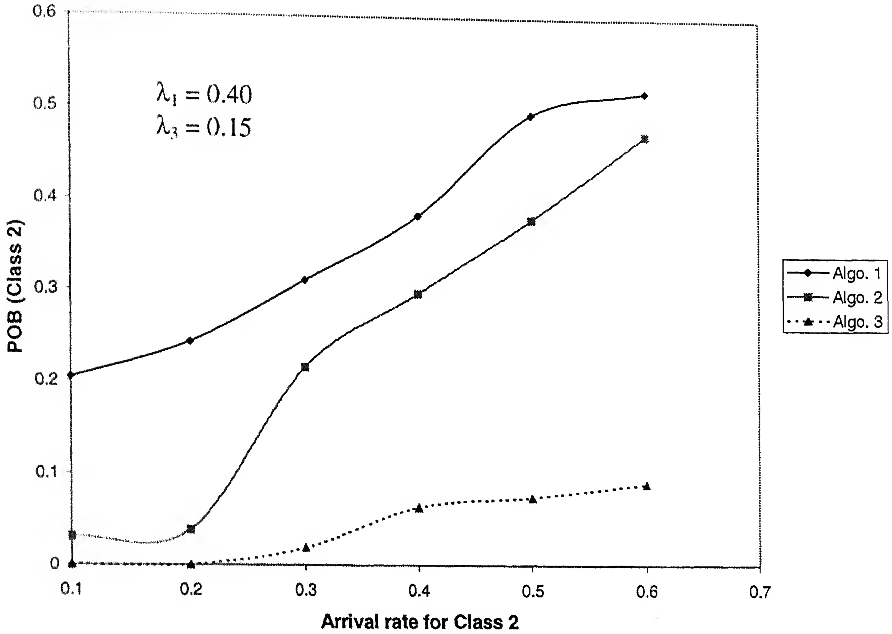


Fig. 5.20: Relative performance for class 2

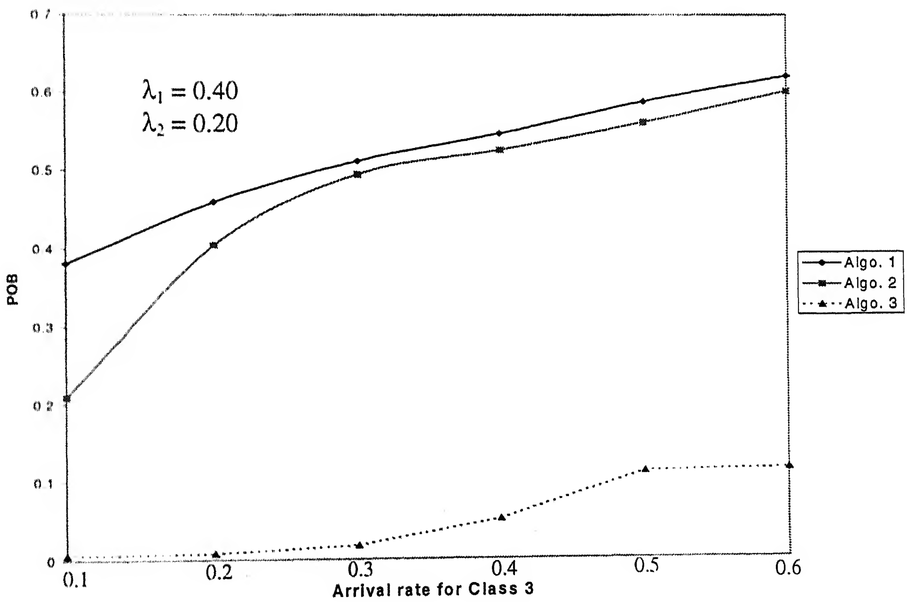


Fig. 5.21: Relative performance for class 3

Chapter 6

Conclusion and Future Scope:

In this work we analyzed three power allocation algorithms for the forward link of Wideband CDMA networks, viz, static algorithm with power reservation, dynamic algorithm and dynamic allocation with data buffering. Our study shows that no single scheme for power allocation is suitable for both voice and high bit rate data traffic. Static algorithm with power reservation is best one for voice traffic, while dynamic algorithm with buffers for data at the base station is best for data traffic. A mix of these two can provide the desirable performance.

Hence we conclude that reserving a separate pool of power for voice traffic and allocating remaining power dynamically to the data user, with buffers inducted at the base station, is a viable solution for the next generation CDMA access networks.

6.1 Future Scope:

The field of research in this area has several aspects and offer fruitful challenges. In our opinion, the present work can be extended in many ways. Some possible directions are:

- Cell sectorization and soft handover can also be incorporated for study.
- This work can also be carried out for reverse link analyses.
- Base stations can increase/decrease maximum transmission power limit under low/high load conditions of adjacent cells.
- To further enhance performance, spot beam concept, which is in the early stage of development, can be incorporated for interference analyses.
- User admission policy can be modified by keeping received E_b/N_0 at a low value if sufficient power is not available and increasing it gradually to the defined level.

Appendix A

A.0 Pareto Distribution:

The Pareto Distribution has been commonly used in monitoring production process. For example, a machine that produces copper wire will occasionally generate a flaw at some point along the length of wire. Pareto distribution can be used to model the length of wire between successive flaws.

Recently much work has been done for the modeling of packet length in WWW application. Statistical analyses have shown that packet length in WWW data stream can be modeled as Pareto distribution.

Probability density function P(x) , and Cumulative distribution function D(x) are defined, over the interval $x \geq b$, as:

$$P(x) = \frac{a.b^a}{x^{a+1}} \tag{A.1}$$

$$D(x) = 1 - \left(\frac{b}{x}\right)^a \tag{A.2}$$

Figure A.1 shows plot of P(x) and D(x) for different values of shape parameter a.
Various Raw (Non-central) moments of Pareto distribution are:

$$\mu'_1 = mean = \frac{a.b}{(a-1)} \tag{A.3}$$

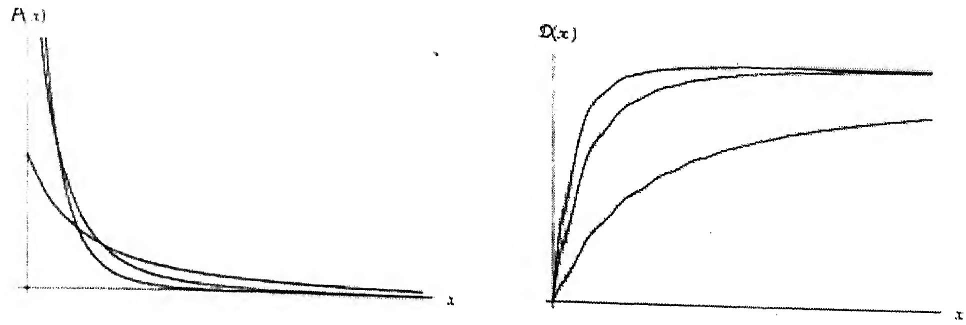


Fig A.1: Pareto Distribution (a) pdf (b) CDF

$$\mu_2' = \frac{a.b^2}{a-2} \tag{A.4}$$

$$\mu_3' = \frac{a.b^3}{a-3} \tag{A.5}$$

$$\mu_4' = \frac{a.b^4}{a-4} \tag{A.6}$$

And the central moments are:

$$\mu_2 = \text{variance} = \frac{a.b^2}{(a-1)^2(a-2)} \tag{A.7}$$

$$\mu_3 = \frac{2a(a+1)b^3}{(a-1)^3(a-2)(a-3)} \tag{A.8}$$

$$\mu_4 = \frac{3a(3a^3+a+2)b^4}{(a-1)^4(a-2)(a-3)(a-4)} \tag{A.9}$$

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